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PHILOSOPHICAL

TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCLI.

PART I.

LONDON:

PRINTED BY RICHARD TAYLOR, RED LION COURT, FLEET STREET.

MDCCCLI.

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ADVERTISEMENT.

The Committee appointed by the *Royal Society* to direct the publication of the *Philosophical Transactions,* take this opportunity to acquaint the Public, that it fully appears, as well from the Council-books and Journals of the Society, as from repeated declarations which have been made in several former *Transactions,* that the printing of them was always, from time to time, the single act of the respective Secretaries till the Forty-seventh Volume; the Society, as a Body, never interesting themselves any further in their publication, than by occasionally recommending the revival of them to some of their Secretaries, when, from the particular circumstances of their affairs, the *Transactions* had happened for any length of time to be intermitted. And this seems principally to have been done with a view to satisfy the Public, that their usual meetings were then continued, for the improvement of knowledge, and benefit of mankind, the great ends of their first institution by the Royal Charters, and which they have ever since steadily pursued.

But the Society being of late years greatly enlarged, and their communications more numerous, it was thought advisable that a Committee of their members should be appointed, to reconsider the papers read before them, and select out of them such as they should judge most proper for publication in the future *Transactions*; which was accordingly done upon the 26th of March 1752. And the grounds of their choice are, and will continue to be, the importance and singularity of the subjects, or the advantageous manner of treating them; without pretending to answer for the certainty of the facts, or propriety of the reasonings, contained in the several papers so published, which must still rest on the credit or judgement of their respective authors.

It is likewise necessary on this occasion to remark, that it is an established rule of the Society, to which they will always adhere, never to give their opinion, as a Body, upon any subject, either of Nature or Art, that comes before them. And therefore the thanks, which are frequently proposed from the Chair, to be given to the authors of such papers as are read at their accustomed meetings, or to the persons through whose hands they received them, are to be considered in no other light than as a matter of civility, in return for the respect shown to the Society by those communications. The like also is to be said with regard to the several projects, inventions, and curiosities of various kinds, which are often exhibited to the Society; the authors whereof, or those who exhibit them, frequently take the liberty to report and even to certify in the public newspapers, that they have met with the highest applause and approbation. And therefore it is hoped that no regard will hereafter be paid to such reports and public notices; which in some instances have been too lightly credited, to the dishonour of the Society.

The Meteorological Journal hitherto kept by the Assistant Secretary at the Apartments of the Royal Society, by order of the President and Council, and published in the Philosophical Transactions, has been discontinued. The Government, on the recommendation of the President and Council, has established at the Royal Observatory at Greenwich, under the superintendence of the Astronomer Royal, a Magnetical and Meteorological Observatory, where observations are made on an extended scale, which are regularly published. These, which correspond with the grand scheme of observations now carrying out in different parts of the globe, supersede the necessity of a continuance of the observations made at the Apartments of the Royal Society, which could not be rendered so perfect as was desirable, on account of the imperfections of the locality and the multiplied duties of the observer.

A List of Public Institutions and Individuals, entitled to receive a copy of the Philosophical Transactions of each year, on making application for the same directly or through their respective agents, within five years of the date of publication.

Observatories.

Armagh.
Cape of Good Hope.
Dublin.
Edinburgh.
Greenwich.
Madras.

Institutions.

Barbadoes	Library and Museum.
Calcutta	Asiatic Society.
Cambridge	Philosophical Society.
Dublin	Royal Dublin Society.
	Royal Irish Academy.
Edinburgh	Royal Society.
London	Admiralty Library.
	Chemical Society.
	Entomological Society.
	Geological Society.
	Geological Survey of Great Britain.
	Horticultural Society.
	Institute of British Architects.
	Institution of Civil Engineers.
	Linnean Society.
	London Institution.
	Medical and Chirurgical Society.
	Queen's Library.
	Royal Asiatic Society.
	Royal Astronomical Society.
	Royal College of Physicians.
	Royal Geographical Society.
	Royal Institution of Great Britain.
	Royal Society of Literature.
	Society of Antiquaries.
	Society for the Encouragement of Arts.
	United Service Museum.
	Zoological Society.
Manchester	Literary and Philosophical Society.
Oxford	Ashmolean Society.
	Radcliffe Library.
Swansea	Royal Institution.
Woolwich	Royal Artillery Library.

Belgium.

Brussels	Royal Academy of Sciences.

Denmark.

Altona	Royal Observatory.
Copenhagen	Royal Society of Sciences.

France.

Paris	Academy of Sciences.
	Dépôt de la Marine.
	Ecôle des Mines.
Paris	Entomological Society.
	Geographical Society.
	Geological Society.
	Jardin des Plantes.
Toulouse	Academy of Sciences.

Germany.

Bonn	Cæsarean Acad. of Naturalists.
Göttingen	University.
Mannheim	Observatory.
Munich	Royal Academy of Sciences.

Italy.

Naples	Institute of Sciences.
Milan	Institute of Sciences, Letters and Arts.
Modena	Italian Society of Sciences.
Turin	Royal Academy of Sciences.

Netherlands.

Amsterdam	Royal Institute.
Rotterdam	Batavian Society of Experimental Philosophy.

Prussia.

Berlin	Royal Academy of Sciences.
	Society of Experimental Philosophy.

Portugal.

Lisbon	Royal Academy of Sciences.

Russia.

Pulkowa	Observatory.
St. Petersburgh	Imperial Academy of Sciences.

Spain.

Cadiz	Observatory.

Sweden and Norway.

Drontheim	Royal Society of Sciences.
Stockholm	Royal Academy of Sciences.

Switzerland.

Geneva	Société de Phys. et d'Hist. Naturelle.

United States.

Boston	American Academy of Sciences.
Cambridge	Harvard University.
Philadelphia	American Philosophical Society.
Washington	Smithsonian Institution.
	Observatory.

The *fifty* Foreign Members of the Royal Society.

A List of Public Institutions and Individuals, entitled to receive a copy of the Astronomical Observations (including Magnetism and Meteorology) made at the Royal Observatory at Greenwich, on making application for the same directly or through their respective agents, within two years of the date of publication.

Observatories.

Altona.
Armagh.
Berlin.
Breslau.
Brussels.
Cadiz.
Cambridge.
Cape of Good Hope.
Coimbra.
Copenhagen.
Dorpat.
Dublin.
Edinburgh.
Helsingfors.
Königsberg.
Madras.
Mannheim.
Marseilles.
Milan.
Munich.
Oxford.
Palermo.
Paris.
Seeberg.
Trevandrum.
Tübingen.
Turin.
Vienna.
Wilna.

Institutions.

Aberdeen	University.
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Bologna	Academy.
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Dublin	University.
Edinburgh	University.
	Royal Society.
Glasgow	University.
Göttingen	University.
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Paris	Academy of Sciences.
	Board of Longitude.
	Dépôt de la Marine.
Philadelphia	American Philosophical Society.
St. Andrews	University.
St. Petersburgh	Imperial Academy.
Stockholm	Royal Academy of Sciences.
Upsal	Royal Society.
Waterville (U.S.)	College.

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Plumian Professor of Astronomy	
President of the Royal Society	London.
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South, Sir James	Kensington.

List of Observatories, Institutions and Individuals, entitled to receive a Copy of the Magnetical and Meteorological Observations made at the Royal Observatory, Greenwich.

Observatories.

Bombay	Capt. Monthiou.
Barnaoul	M. Prang, 1st.
Cairo	M. Lambert.
Cambridge, United States	Prof. Lovering.
Catherineburgh	M. Rochkoff.
Christiania	M. Hansteen.
Cincinnati	Dr. Locke.
Gotha	
Hammerfest	
Heidelberg	M. Tiedemann.
Hobarton	Commander Kay, R.N.
Kasan	M. Simonoff.
Kew	F. Ronalds, Esq.
Kremsmünster	Prof. Koller.
Leipsic	
Marburg	Prof. Gerling.
Nertchinsk	M. Prang, 2nd.
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Pekin	M. Gachkévitche.
Prague	M. Kreil.
Pulkowa	M. Struve.
St. Petersburgh	M. Kupffer.
Sitka	Messrs. Homann and Ivanoff.
Stockholm	Prof. Selander.
Teflis	M. Philadelphine.
Toronto	Captain Lefroy, R.A.
Upsal	Prof. Svanberg.
Warsaw	Col. G. Du Plat (British Consul).
Washington	Lt. Maury, U.S. Navy.

Institutions.

Bombay	Geographical Society.
Bonn	University.
Bowditch Library	United States.
Cambridge	Library, Philosophical Society.
Cherkow	University.
Kiew	University.
London	House of Lords, Library.
	House of Commons, Library.
	King's College.
London	Royal Institution.
	Royal Society.
	University.
Moscow	University.
Royal Cornwall Polytechnic Society	
St. Bernard	Convent.
St. Petersburgh	Geographical Society.
Washington	Smithsonian Institution.
Woolwich	Office of Mag. and Met. Publication.

Individuals.

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Mentchikoff, Prince	St. Petersburgh.
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Quetelet, A.	Brussels.
Redfield, W. C., Esq.	New York.
Reid, Lieut.-Col., R.E.	London.
Riddell, Capt., R.A.	Woolwich.
Roget, P. M., M.D.	London.
Sabine, Lieut.-Col., R.A.	Woolwich.
Senftenberg, Baron von	Prague.
Wartmann, Prof. Elie	Geneva.
Wrangell, Vice-Admiral	St. Petersburgh.
Younghusband, Capt., R.A.	Woolwich.

ROYAL MEDALS.

HER MAJESTY QUEEN VICTORIA, in restoring the Foundation of the Royal Medals, has been graciously pleased to approve the following regulations for the award of them:

That the Royal Medals be given for such papers only as have been presented to the Royal Society, and inserted in their Transactions.

That the triennial Cycle of subjects be the same as that hitherto in operation: viz.

1. Astronomy; Physiology, including the Natural History of Organized Beings.
2. Physics; Geology or Mineralogy.
3. Mathematics; Chemistry.

That, in case no paper, coming within these stipulations, should be considered deserving of the Royal Medal, in any given year, the Council have the power of awarding such Medal to the author of any other paper on either of the several subjects forming the Cycle, that may have been presented to the Society and inserted in their Transactions; preference being given to the subjects of the year immediately preceding: the award being, in such case, subject to the approbation of Her Majesty.

The Council propose to give one of the Royal Medals in the year 1851 for the most important paper in Astronomy, communicated to the Royal Society after the termination of the Session in June 1847, and prior to the termination of the Session in June 1850, and printed in the Philosophical Transactions.

The Council propose also to give one of the Royal Medals in the year 1851 for the most important paper in Physiology, including the Natural History of Organized

Beings, communicated to the Royal Society after the termination of the Session in June 1847, and prior to the termination of the Session in June 1850, and printed in the Philosophical Transactions.

The Council propose to give one of the Royal Medals in the year 1852 for the most important paper in Physics, communicated to the Royal Society after the termination of the Session in June 1848, and prior to the termination of the Session in June 1851, and printed in the Philosophical Transactions.

The Council propose also to give one of the Royal Medals in the year 1852 for the most important paper in Geology or Mineralogy, communicated to the Royal Society after the termination of the Session in June 1848, and prior to the termination of the Session in June 1851, and printed in the Philosophical Transactions.

ADJUDICATION of the MEDALS of the ROYAL SOCIETY for the year 1851 by the PRESIDENT and COUNCIL.

The COPLEY MEDAL to Professor OWEN, for his important discoveries in Comparative Anatomy and Palæontology, contained in the Philosophical Transactions and numerous other works.

The ROYAL MEDAL in the department of Astronomy, to The EARL OF ROSSE, for his "Observations on the Nebulæ," published in the Philosophical Transactions for the year 1850.

The ROYAL MEDAL in the department of Physiology, to GEORGE NEWPORT, Esq., for his paper "On the Impregnation of the Ovum in the Amphibia" (First Series), published in the Philosophical Transactions for the year 1851.

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ERRATA.

Page 397, line 9 from the bottom, *for* garnet-octohedrons *read* garnet-dodecahedrons.
—— 398, line 13 from the bottom, *for* $(H_4 N)_2$ *read* $(H_4 N)$.
—— 500, line 16, *for* J *read* $\frac{dJ}{dr}$.
In Art. 6, page 519, change β to β_1 wherever it is a factor of quantities containing Y_2 or other terms in the development of y.
Page 522, line 13 from bottom, *for* c_1 *read* C_1.
—— 531, line 14 from bottom, *for* (23.) *read* (33.).
—— 539, line 2 from bottom, *for* j_2 *read* j.
—— 703, *for* Hewitt *read* Hewett; *for* Beautems Beaupres *read* Beautemps Beaupré; *for* Engineurs *read* Ingenieurs; *for* Françaíse *read* Français.
—— 709 and 712, *for* Lemon *read* Leman.

PHILOSOPHICAL TRANSACTIONS.

I. The Bakerian Lecture.—*Experimental Researches in Electricity.—Twenty-fourth Series. By* Michael Faraday, *Esq., D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Ord. Boruss. Pour le Mérite, Eq., Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, Munich, Bruxelles, Vienna, Bologna, &c. &c.*

Received August 1,—Read November 28, 1850.

§ 30. *On the possible relation of Gravity to Electricity.*

2702. THE long and constant persuasion that all the forces of nature are mutually dependent, having one common origin, or rather being different manifestations of one fundamental power (2146.), has made me often think upon the possibility of establishing, by experiment, a connection between gravity and electricity, and so introducing the former into the group, the chain of which, including also magnetism, chemical force and heat, binds so many and such varied exhibitions of force together by common relations. Though the researches I have made with this object in view have produced only negative results, yet I think a short statement of the matter, as it has presented itself to my mind, and of the result of the experiments, which offering at first much to encourage, were only reduced to their true value by most careful searchings after sources of error, may be useful, both as a general statement of the problem, and as awakening the minds of others to its consideration.

2703. In searching for some principle on which an experimental inquiry after the identification or relation of the two forces could be founded, it seemed that if such a relation existed, there must be something in gravity which would correspond to the dual or antithetical nature of the forms of force in electricity and magnetism. To my mind it appeared possible that the ceding to the force or the approach of gravitating bodies on the one hand, and the effectual reversion of the force or separation of the bodies on the other, might present the points of correspondence; quiescence (as to motion) being the neutral condition. The final unchangeability of gravity did not seem affected by such an assumption; for the acting bodies when at rest would ever have the same relation to each other, and it would only be at the times of motion to and fro that any results related to electricity could be expected. Such results, if possible, could only be exceedingly small; but, *if possible*, i. e. if true, no terms could exaggerate the value of the relation they would establish.

2704. The thought on which the experiments were founded was, that, as two bodies moved towards each other by the force of gravity, currents of electricity might be developed either in them or in the surrounding matter in one direction; and that as they were by extra force moved from each other against the power of gravitation, the opposite currents might be produced. Also, that these currents would have relation to the line of approach and recession, and not to space generally, so that two bodies approaching would have currents in the opposite direction as to space generally, but the same as to the direction of their motion along the line joining them. It will be unnecessary to go further into the suppositions which arose concerning these points, or regarding the effect of forced motions either coinciding with, or across the direction of the earth's gravitation, and many other matters, than to say that, as the effect looked for was exceedingly small, so no hope was entertained of any result except by means of the gravitation of the earth. The earth was therefore made to be the one body, and the indicating mass of matter to be experimented with the other.

2705. First of all, a body, which was to be allowed to fall, was surrounded by a helix, and then its effect in falling sought for. Now a body may either fall with a helix or through a helix. Covered copper wire, to the amount of 350 feet in length, was made into a hollow cylindrical helix, about 4 inches long, its internal diameter being 1 inch and its external diameter 2 inches. It was attached to a line running upon an easy pulley, so that it could be raised 36 feet, and then allowed to fall with an accelerated velocity on to a very soft cushion, its axis remaining vertical the whole time. Long covered wires were made fast to its two extremities, and these being twisted round each other, were attached to a very delicate galvanometer, placed about 50 feet aside from the line of fall, and on a level midway with its course. The accuracy of the connection and the direction of the set of the needle, were then both ascertained by the introduction of a feeble thermo-electric combination into the current. Such a helix, either in rising or falling, can produce no deviation at the galvanometer by any current due to the magnetism of the earth; for as it remains parallel to itself during the fall, so the lines of equal magnetic force, which being parallel to the dip, are intersected by the wire convolutions of the descending helix, are cut with an equal velocity on both sides of the helix, and consequently no effect of magneto-electric induction is produced. Neither in rising nor in falling did this helix present any trace of action at the galvanometer; whether the connection with the galvanometer was continued the whole time, or whether it was cut off just before the diminution or cessation of motion either way, or whether the rising and the falling were made to occur isochronously with the times of vibration of the galvanometer needle. So, though no effect of gravity appeared in the helix itself, still no source of error appeared to arise in this mode of using it.

2706. A solid cylinder of copper, three-fourths of an inch in diameter and 7 inches in length, was now introduced into the helix and carefully fastened in it, being bound round with a cloth so as not to move, and this compound arrangement was allowed to fall as before (2705.). It gave very minute but remarkably regular indications of a current at the galvanometer; and the probability of these being related to gravity appeared the greater, when it was found that on raising the helix or core, similar indications of contrary currents appeared. It was some time before I was able to refer these currents to their true cause, but at last I traced them to the action of a part of the connecting wires proceeding from the helix to the galvanometer. The two wires had been regularly twisted together, but the effect of many falls had opened a part near the middle distance into a sort of loop, so that the wires, instead of being tightly twisted together like the strands of a rope, were separate for 3 feet, as if the strands were open. In falling, this loop opened out more or less, but always in the same manner; and the consequence was that the part of it representing the transverse opening, which was furthest from the galvanometer, travelled over a larger space than the corresponding part nearest the galvanometer. Now had they travelled through equal spaces, the effect of the magnetic lines of force of the earth upon them would have been equal, and no effect at the galvanometer would have been produced; as it was, currents in opposite directions, but of unequal amounts of force, tended to be produced, and a current equal to the difference actually appeared. Such a case is described in my earliest researches on terrestrial magno-electro induction (171.). It is evident that the current should appear in the reverse direction, as the helix and wires are raised in the air, and thus arose the reverse effect described above. Therefore no positive or favourable evidence was supplied in favour of the original assumption by this use of a copper core in the helix.

2707. The copper was selected as a heavy body and an excellent conductor of electricity. On its dismissal, a bismuth cylinder of equal size was employed to replace it as a substance eminently diamagnetic, and a bad conductor amongst metals. Uncertain evidence arose; but by close attention, first to one point and then to another, all the indications disappeared, and then the rising or falling of the bismuth produced no effect on the galvanometer.

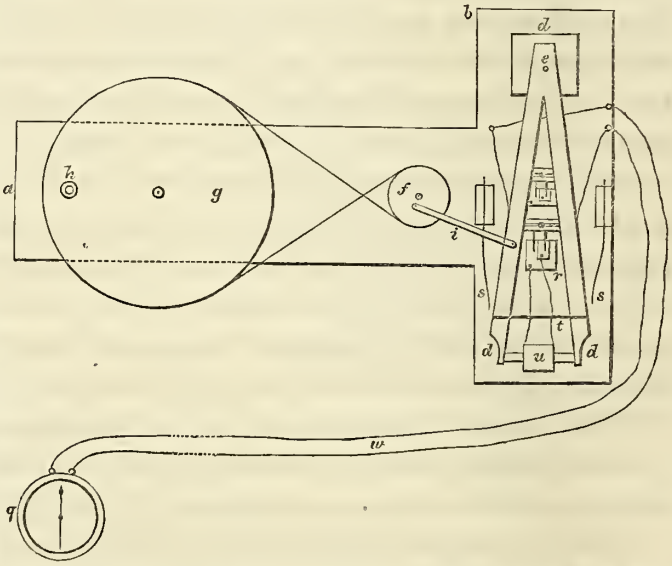
2708. An *iron* cylinder was also employed as a magnetic metal, but when made perfectly secure, so as to prevent any motion relative to the helix, it was equally indifferent with the copper and bismuth (2706. 2707.).

2709. Cylinders of glass and shell-lac were employed as non-conducting substances, but without effect.

2710. In other experiments the helix was *fixed*, and the different substances in the form of cylinders, three-fourths of an inch in diameter and 24 inches long, were dropped through it, or else raised through it with an accelerated velocity; but in neither case was any effect produced. Rods of copper, bismuth, glass, shell-lac and sulphur were employed. Occasionally these rods were made to rotate rapidly before and during their fall; and many other conditions were devised and carried into effect, but always with negative results, when sources of error were avoided or accounted for.

2711. On further consideration of the original assumption, namely, a relation between the forces, and of the effects that might be looked for consequent upon a condition of tension in and around the particles of the body, which, as we know, are at the same moment the residence of both gravitating and electric forces, and are subject to the gravitation of the earth, it seemed probable that the stopping of the up and down motion (2703. 2704.) in the line of gravity would produce contrary effects to the coming on of the motion, and that, whether the stopping was sudden or gradual; also that a motion downward quicker than that which gravity could communicate, would give more effect than the gravity result by itself, and that a corresponding increase in the velocity upwards would be proportionally effectual. In such case a machine which could give a rapid alternating up and down motion, might be very useful in producing many minute units of inductive action in a small space and moderate time; for then, by proper commutators, the accelerated and retarded parts of each half-vibration could be separated and recombined into one consistent current, and this current could be sent through the galvanometer during the time its needle was swinging in one direction, and afterwards reversed for the time of a swing in the other direction; and so on alternately until the effect had become sensible, if any were produced by the assumed cause.

2712. The machine which I had made for this purpose is that described in the last Series of these Researches (2643.), the electro-magnet, the experimental core and the rod which carried them being removed :—*a*, *b*, *c* frame-board; *d*,*d*,*d* wooden lever, of which *e* is the axis; *f* the crank-wheel, and *g* the great wheel with its handle *h*; *i* the bar connecting the crank-wheel and lever; *q* the galvanometer; *r* the commutator; *w*, connecting wires; *s*, *s* springs of brass or copper; *t* a copper rod connecting the two arms of the lever to give strength; *u* the hollow helix fixed, or moveable at pleasure. The plan is to a scale of one-fifteenth. Being on a



moveable frame, it could be placed in any position. The cylinder of metal or other substance to be submitted to its action, was 5½ inches long and three-fourths of an inch in diameter, and was firmly held between the ends *d, d* of the lever arms. The extent of the alternating motion was 3 inches. A hollow cylindrical helix *u*, 2½ inches in length, and of such internal diameter that the cylinders could complete their rapid journeys to and fro within it without any danger of striking against its sides, was constructed, containing 516 feet of covered copper wire; this cylinder could be either fixed immoveably or attached firmly to the cylinder under experiment so as to move with it. The wires from this helix passed to the commutators and from them to the galvanometer. Part of the momentum of this machine was taken up by springs *s, s* (2648.), and converted into the contrary motion; but so much remained undisposed of thus, that great care was required in fixing and strutting to render the action of the whole very steady, or else derangement quickly occurred at the cylinder and helix, and electro-currents were frequently produced.

2713. The employment of cylinders of iron, copper and other substances in this machine, was competent to produce electro-currents in various ways. Thus, iron might produce magneto-electric currents consequent upon its polar condition under the influence of the earth; these it would be easy to detect and separate by the use of adjusted magnets, which should neutralize or reverse the lines of magnetic force passing through the iron. Currents like those induced in copper cylinders and good conductors (2663. 2684.), might be produced by the earth's action; but as the lines of gravitating force and of terrestrial magnetic force are inclined to each other, these might be separated by position; and it appeared that there was no source of error that might not by care be eliminated. I will not occupy time by describing how this long lesson of care was learned, but pass at once to the chief results.

2714. The copper cylinder (2712.) was placed in the machine, and the helix fixed immoveably around it, the whole being in such a position that the cylinder should be vertical, and move up and down parallel to the line of gravitating force within the helix. However rapidly the machine was worked, or whatever the position of the commutator, there was no result at the galvanometer. Cylinders of bismuth, glass, sulphur, gutta percha, &c., were also employed, but with the same negative conclusion.

2715. Then the helix was taken from its fixed support and fastened on to the copper cylinder so as to move with it, and now very regular and comparatively large effects were produced. After a while, however, these were traced to causes other than gravity, and of the following kind. The helix was fixed at one end of a lever, at a point 22 inches from its axis, and being 2 inches in diameter its wires on one side were only 21 inches, and on the other side 23 inches from this axis. Hence, in vibrating these parts travelled with velocities and through spaces which are as 21 : 23. When therefore their paths were *across* the lines of magnetic force of the earth, electro-currents tended to form in these different parts proportionate in amount or strength to these numbers; and the differences of these currents being continually gathered up by the commutators, were made sensible at the galvanometer. This was rendered manifest by placing the machine so, that though the plane of vibration was still vertical, the place of the helix was just under the centre of motion, and the central line of the helix therefore, instead of being vertical, was horizontal. Now the convolutions of the helix cut the lines of magnetic force in the most favourable manner; and the consequence was that the commutators were not required, for a single motion of the helix in one direction was sufficient to show at the galvanometer the magneto-electric currents induced. If, on the contrary, the plane of motion was made horizontal, then no current was produced by any amount of motion; for though the helix was as horizontal as, and not sensibly more so than before, yet the parts of the convolutions which intersected the magnetic lines of force (being the upper and the lower parts) now moved with exactly equal velocity, and no differential result was produced.

2716. The former small result (2715.) was therefore probably dependent upon an effect of this kind; and this was confirmed by placing the machine in such a position that the axis of the moving copper cylinder and helix should in its medium position be parallel to the line of the dip, and then no effect was produced. Other bodies in the same position were equally unable to produce any effect.

2717. Here end my trials for the present. The results are negative. They do not shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists.

Royal Institution,
July 19, 1850.

II. *Experimental Researches in Electricity.—Twenty-fifth Series. By* Michael Faraday, *Esq., D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Ord. Boruss. Pour le Mérite, Eq., Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, Munich, Bruxelles, Vienna, Bologna, &c. &c.*

Received August 15,—Read November 28, 1850.

§ 31. *On the magnetic and diamagnetic condition of bodies.*

¶ i. *Non-expansion of gaseous bodies by magnetic force.* ¶ ii. *Differential magnetic action.* ¶ iii. *Magnetic characters of Oxygen, Nitrogen and Space.*

¶ i. *Non-expansion of gaseous bodies by magnetic force.*

2718. THERE can be no doubt that the magnetic force, the diamagnetic force, and the magneoptic or magnecrystallic force, will, when thoroughly understood, be found to unite or exist under one form of power, and be essentially the same. Hence the great interest which exists in the development of any one of these modes of action; for differing so greatly as they do in very peculiar points, it is hardly possible that any one of them should be advanced in its illustration or comprehension, without a corresponding advance in the knowledge of the others. Stimulated by such a feeling, I have been engaged with Plücker, Weber, Reisch and others, in endeavouring to make out, with some degree of precision, the mode of action of diamagnetic as well as magnecrystallic bodies; and the recent investigation (2640, &c.) and endeavour to confirm the idea of polarity in bismuth and diamagnetic bodies, the reverse of that in a magnet or in iron bodies, was one of the results of that conviction and desire.

2719. Having failed however to establish the existence of such an antipolarity, and having shown, as I think, that the phenomena which were supposed to be due to it are in fact dependent upon other conditions and causes, I was induced, in the search after something precise as to the nature of diamagnetic bodies, to examine another idea which had arisen in consequence of the development of magnetic and diamagnetic phenomena amongst gaseous substances: this thought, with some of the results which have grown out of it during its experimental examination, I purpose making the subject of the present paper.

2720. Bancalari first showed that flame was diamagnetic[*]. The effect, as I proved, was due chiefly to the heated state of gaseous portions of the flame[†]; but besides that, it appeared that at common temperatures diamagnetic phenomena could be exhibited by gases; and also that in their production the gases differed very much one from another*; so that, taking common air, for instance, as a standard, nitrogen, and many other gases, were strongly diamagnetic in relation to it, whilst oxygen took on the appearance of a magnetic body; for *they* were repelled from, while it was attracted to, the place of maximum force in the magnetic field.

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[*] Philosophical Magazine, 1847, vol. xxxi. pp. 401, 421.

[†] Ibid. pp. 404, 406.

2721. Recalling the general law given respecting the action of magnetic and diamagnetic bodies (2267, 2418), namely, that the former tended to go from weaker to stronger places, and the latter from stronger to weaker places of magnetic power, and applying it to such bodies as the gases, which are at the same time both highly elastic and easily changed in bulk by the superaddition of very small degrees of force, it would seem to follow, that if the particles of a diamagnetic gas tended to go from strong to weak places of action, in consequence of the direct and immediate effect of the magnetic power on them, then such a gas should tend to become enlarged or expanded in the magnetic field. For the amount of power by which the particles would tend to recede from the axis of the magnetic field, would be added to the expansive force by which they before resisted the pressure of the atmosphere; that pressure would therefore be in part sustained by the new force, and expansion would of necessity be the result. On the other hand, if a gas were magnetic (as for instance oxygen), then the force cast upon the particles, by such a direct and immediate action of the magnetic power upon them, would urge them *towards* the axis of the magnetic field, and so coinciding with, and being superadded to the pressure of the atmosphere, would tend to cause contraction and diminution of bulk.

2722. If such supposititious cases were to prove true, we should then be able to arrive at the knowledge of the real zero-point (2416, 2432, 2440)†, not amongst gases only, but amongst all bodies, and should be able to tell whether such a gas as oxygen were a magnetic or a diamagnetic body, and also able to range individual gases and other substances in their proper places. And though I had originally endeavoured to ascertain whether there was any change in the bulk of air in the magnetic field, and found none, still PLÜCKER's statement that he has obtained such an effect‡, and the great enlargement of knowledge respecting the gases which since then we have acquired relating to their diamagnetic relations, and especially of the great difference which exists between them, encouraged me to proceed.

2723. I first endeavoured to determine whether there was any affection of the layer of air (or other gas) immediately in contact with the magnetic pole, which, either by the consequent expansion or contraction of that layer, could render it able to affect the course of a ray of light and thus make manifest the changes occurring within. A metal screen, with a pin-hole in it, was set up before the flame of a bright lamp in a dark room, and thus an artificial star or small definite luminous object was formed.

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* Philosophical Magazine, 1847, vol. xxxi. p. 409.

† Ibid. p. 420.

‡ Annales de Chimie, 1850, xxix. p. 134.

Forty-six feet from it was placed the great horseshoe magnet (2247.), ready to be excited by twenty pairs of Grove's plates; the poles were in a line, so that the ray from the lamp passed for 4 inches close to the surface of the first pole, then through 6 inches of air, and then, for 4 inches, close to the surface of the second pole. A very fine refracting telescope, belonging to Sir James South, having an aperture of 3 inches and 46 inches focal length, received the ray. The telescope was furnished with a perfect micrometer, so that the smallest change in the place of the luminous image could be observed on the threads. The axis of the telescope was just above the level of the magnetic poles. Not the smallest change in either the character or place of the luminous image could be observed, either on the making or the breaking of the contact between the voltaic battery and the magnetic wire.

2724. As the chief part of the light which came to the telescope consisted of rays which passed at some distance above the magnetic poles, these were cut off by a screen, which rising only one-eighth of an inch above the level of the poles, allowed no ray to pass that was not within that distance. The intensity of the light was of course diminished, and the image was distorted by inflection; still its place was well marked by the micrometer. Not the slightest change in that or any other character occurred in the supervention or the withdrawal of the magnetic force.

2725. The terminals of the magnetic poles were then varied, so that the ray sometimes passed parallel and close to a long right-angled edge, or parallel to and between two right-angled edges, a little above or below them, or over the line joining two hemispherical poles, placed close together (and also in many other ways), but in no case did the magnetic action produce any effect upon the course of the ray.

2726. In another form of the experiment the telescope was dismissed, and a simple card, with a pin-hole $\frac{1}{50}$th or $\frac{1}{100}$th of an inch in diameter, employed in its place. The image of the star of light could be seen through the pin-hole in the dark room, and yet every ray tending to its formation passed within $\frac{1}{50}$th of an inch of the surface of the magnetic pole; still no effect due to the magnetic force could be observed.

2727. By another arrangement of the polar terminations, analogous to one I had formerly employed when experimenting on the diamagnetic relations of the gases*, I was able to surround them with other gaseous substances than air, and subject the ray for 2 inches of its course to these gases whilst under the influence of the magnet. Though the glass of the enclosing vessel disturbed the image of the object, *i. e.* the point of light, yet it was easy to perceive that no additional effect occurred when the magnetism was superinduced.

2728. Oxygen, nitrogen, hydrogen and coal-gas were thus employed; but whether any one of these, or whether air itself was submitted to examination, when in contact with the active pole of a very powerful magnet, it did not appear to be either expanded or condensed to such a degree as to cause any sensible change in its refractive force.

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* Philosophical Magazine, 1847, vol. xxxi. pp. 414, 415.

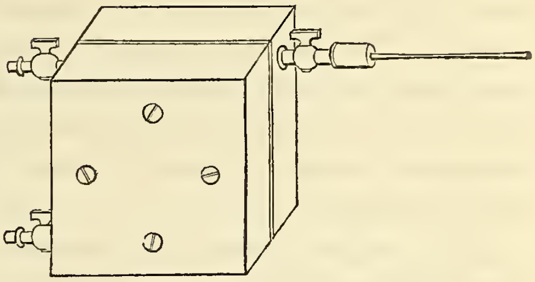
2729. In order to compare the expected result with the real result due to change of volume, I took a bar of iron 7 inches long, and placed it so that the ray from the luminous object in passing to the eye should proceed by the side of the bar at not more than $\frac{1}{50}$th of an inch from it, and then raised the temperature of the bar gradually, until by expanding the air in contact with it, the course of the ray of light was sensibly affected; to do this it required to be exalted many degrees. When the air of the place was at 60° and the iron raised to 100° FAHR., the effect was not distinct. Hence it seemed, that observation of the expected change of volume of the air would be rendered far more sensible by some arrangement, measuring that change directly, than by such means as those referred to above, dependent on refractive force; for it is certain that the change of volume, in a very small quantity of air, raised from 60° to 100°, would be very evident by the former method. On the other hand, it was just possible that if the air or gas was affected by the magnet, it might only be in that film immediately contiguous to the pole; and also that great differences in the degree of change might exist along the *edge* of a solid angle, and along the *sides* of the planes forming that angle. Hence the assumed necessity for examining those parts by a ray of light; and every precaution was taken, by inclining the course of the ray a little more or less to the sides or edges of the poles, and by making the sides or edges very slightly convex, to include every variation of the experiment, that might help to make any magnetic or diamagnetic effect, whether special or local, or general, manifest; but without effect.

2730. I proceeded, as these attempts had failed, to endeavour to determine and compare the *volume* of air subjected to the magnetic force, before and after its subjection; and there seemed to be the greater hope of obtaining some results in this way, provided any such change was a consequence of the action of magnetic power, because air and gases, at a considerable distance from the surface of the magnet, are known to be strongly affected diamagnetically, and because PLÜCKER had already said he had obtained such change of volume (2722.).

2731. The first instrument constructed for this purpose was of the following kind. Two blocks of soft iron, each 1 inch thick and 3 inches square, having filed and flattened surfaces, were prepared; and also a sheet of copper, $\frac{1}{60}$th of an inch in thickness and 3 inches square, having its middle part cut away to within 0·3 of an inch of the edge all round. This plate or frame was then placed between the iron blocks, and the whole held together very tightly by copper screws, so as to make an air-chamber $\frac{1}{60}$th of an inch wide and 2·4 inches square, having the faces of the blocks, which were to become the magnetic poles, for its sides. Three apertures and corresponding passages gave access to the interior of this chamber; small stopcocks were attached to each. By two of these, any gas, after it had been properly dried, could be sent into the chamber, or swept out of it, by any other entering gas;

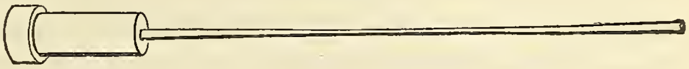
and to the third was attached a gauge (2732.) for the purpose of indicating and measuring any change of volume which might occur. The edges of the central copper plate and the heads of the countersunk screws, were touched with white hard varnish, and the chamber thus rendered perfectly tight, under every condition to which it had to be subjected (fig. 1).

Fig. 1.



2732. The gauges were formed of small capillary tubes from 1·5 to 3 inches in length, the diameter in the middle of their length being less than one-half of that at either termination. These were fixed at one end into a small socket, which screwed on to the third, or gauge-cock mentioned above (2731.). A minute portion of spirit, coloured by cochineal, being put into the external end of this gauge, from a slip of wood or glass, immediately advanced to the middle or narrowest part, forming, as it always should do, a single portion of fluid. By shutting the cock, this little cylinder could be easily retained in its place undisturbed during the filling of the air-chamber with gas, and the adjustment of its pressure to equality with that of the atmosphere. On shutting the other cocks and opening the gauge-cock, the gauge was then ready to show any change of volume which the supervention of the magnetic force might cause; but to give it the highest degree of sensibility, it was necessary previously to make the liquid cylinder travel right and left of its place of rest, that the tube might be moistened on each side of the indicating fluid; an effect easily obtained by inclining the chamber to and fro, the gravity of the fluid making it pass one way or the other. But this and many other necessary precautions as to position, temperature, &c., can only be learned from experience.

Fig. 2.



2733. When this box was in its place, it stood between the poles of the great electro-magnet, with the plane of the gas-chamber in the equatorial position; then square blocks of soft iron, resting on the magnet poles, were made to abut and bear against the sides of the box, so that in fact the inner faces of the air-chamber were the virtual magnetic poles, and being 3 inches square were only $\frac{1}{60}$th of an inch apart. Hence, whatever air or gas was within the chamber, would be subjected to a very powerful magnetic action, and could have very small changes in its bulk measured; but it is perhaps necessary to observe, that it would be contained in a field having everywhere lines of equal magnetic power (2463. 2465.).

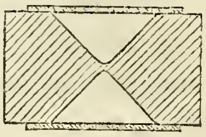
2734. *Air* was introduced into the box, and when all was properly arranged, the place of the indicating fluid was observed by a microscope. Then the magnet was rendered powerfully active, and there appeared a very slight motion of the fluid, as if the air were a little expanded; on taking off the magnetic force the fluid returned to its first place. The same effect recurred again and again. The amount of this change was very small, and there was reason to refer it to the pressure exercised by the magnet, when in action, upon the sides of the iron box; for afterwards, when the box was placed in a vice and squeezed, the same motion in the fluid occurred; and further, when the square blocks of soft iron (2733.) were kept apart by an under block of wood, so as not absolutely to touch and press the box, the effect was reduced to almost nothing.

2735. Oxygen, nitrogen, carbonic acid and nitrous oxide gases, were then introduced successively into the iron box, and with exactly the same result as with air. No difference appeared between oxygen and the other gases, greatly as they differ in magnetic and diamagnetic force and relations. Hydrogen and coal-gas were also subjected to experiment; but when these gases were in the box there was a gradual recession of the indicating fluid, due, as I found, to the absorption of the gases, probably either by the varnish or cement or cork used at the gauge, or at the joints of the box. The delicacy of the gauge was thus made manifest; but when the effect was taken into account, it was found that these gases were equally unaffected in bulk as the other gases by the magnetic influence.

2736. The diameter of the gauge, at the place where the fluid was placed, was rather less than $\frac{1}{100}$th of an inch. An amount of motion equal to $\frac{1}{100}$th of an inch was easily discerned. Comparing these numbers with the capacity of the gas-chamber, it would appear that if the gas in the latter had expanded or contracted to the extent of $\frac{1}{100,000}$th part, the result would have been visible; or any *difference* approaching to this amount, between oxygen and nitrogen or the other gases, would have become sensible, *but no such effects or differences appeared.*

2737. As the establishment of either the *occurrence* or the *absence* of change of volume in gases, when under the magnetic influence, appeared to me to be of great and almost equal importance, I was led to consider whether, in the experiment just described, the circumstance of the gases having been subjected to the magnetic power in a field of equal force (2733.) might not have interfered with the production of the effect sought for; for such a field is that where the diamagnetic phenomena, of solid and liquid bodies, occur in the most unfavourable manner, and where indeed they almost entirely disappear. I therefore constructed another apparatus so that this condition was removed, and in which, if the particles of the diamagnetic gas, by any unknown disposition of the powers in action, tended only to pass from strong to weaker places of force, and being thus incapable of enlargement in the axial direction, would only show that effect equatorially, the opportunity for their doing so should be present.

Fig. 3.



2738. A cylinder of soft iron had the central parts removed in a lathe, until it had assumed the form of an hour-glass, or that represented in fig. 3, which is to a scale of one-third. When placed between the poles of the magnet instead of the former box, it was expected that the continuation of the iron throughout would prevent any diminution of its length, from the pressure of the poles (2734.), and that the diamagnetic phenomena would be abundantly produced in the parts from whence the iron had been removed. The latter was found to be the fact, for flame, smoke, bismuth and other diamagnetic matter, when placed there, passed equatorially very freely.

2739. A copper tube, 2·5 inches long, made of metal 0·1 of an inch thick, was fitted to the iron, so that when in its place it should occupy the position represented (fig. 3), and could easily be made perfectly gas-tight by a little soft cement. In this way it formed an annular air-chamber round the iron, which, when measured, was found to have a capacity of rather more than 2 cubic inches, and included the most intense part of the magnetic field. Three stopcocks were fitted into this copper jacket, by two of which gas was passed into and out of the chamber, and the third was appropriated to the pressure-gauge as before. Whilst naked, this apparatus could not be used, because of its ever-varying temperature, and the consequent disturbance and ejectment of the fluid in the gauge; but when clothed in three thicknesses of flannel its temperature was perfectly steady; and by the further use of wooden keys to turn the cocks the apparatus became unexceptionable.

2740. Before proceeding to employ this apparatus with different gases, and in order to obtain some idea of what might be expected by comparing one gas with another, I made a preliminary experiment, dependent on the relative specific gravities of air and hydrogen, of the following nature. It is easy to diffuse a trace of ammonia through the air of a jar, by putting a little paper wetted with a strong solution into it*; and it is equally easy to send a jet of hydrogen, containing the smallest portion of muriatic acid gas, by a horizontal tube into the ammoniated air. When this is done, the course of the light hydrogen in the heavy air is rendered very distinctly visible; and it is seen, on leaving the horizontal tube, to turn at once upwards and to ascend rapidly, becoming wire-drawn in its course, in consequence of its small specific gravity compared to air.

2741. Two hemispherical iron pole terminations, associated with the great magnet, were then placed in contact with each other, so that they might be surrounded either by air or oxygen†, and the jet of hydrogen, delivering at the rate of 6 cubic inches per minute, was placed exactly beneath the axial line, in the centre of the magnetic field. When there was no magnetic force employed the hydrogen rose vertically, breaking against the points where the hemispherical poles touched; but when the magnetic power was on, the stream of hydrogen divided into two parts, moving right and left, and ascended in two streams at a distance from the point of contact. Now this division took place at a certain distance *below* the axial line; and at that point, notwithstanding the ascensive power of hydrogen in air or oxygen, it was constrained to go horizontally by the apparently repulsive power of the magnetic force, and did not in its further course approach nearer to the axial line, but formed a curve concentric with it, or nearly so, so that the compound streams of gas assumed exactly the shape of a tuning-fork.

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* Philosophical Magazine, 1847, vol. xxxi. p. 415,

† Ibid. pp. 413, 414.

2742. When air occupied the magnetic field, the division of the stream of hydrogen was 0·3 or 0·32 of an inch below the axial line. When oxygen was about the poles, then the division of the hydrogen took place as far off as 0·55 of an inch below the axial line. Hence at these distances the power which tended to make the hydrogen pass from the axial line, equatorially in the direction of the radius, was equal to the difference of the specific gravity of hydrogen compared with that of air and oxygen respectively. At lesser distances the power would be much greater; and indeed, if in any experiment the hydrogen was delivered nearer to the axial line, it was blown downwards and away with much force. Calculating with these data, and still assuming that the diamagnetic gases receded from the axial line, in consequence of the direct action of the magnet and that only, causing them to pass from stronger to weaker places of action, I found, as I thought, reason to believe that the more diamagnetic gases, occupying the space within the copper box (2739.), might probably be expanded at least $\frac{1}{60,000}$th part of their volume by the magnetic force. Now the gauges that I employed were sensible when the fluid in them moved the $\frac{1}{100}$th of an inch (2736.), yet that space is only the $\frac{1}{2,500,000}$th part of the capacity of the chamber, and therefore such an expansion as that above would have made it move through 0·4 of an inch; a quantity abundantly sufficient to render the result sensible if the fundamental assumption were correct.

2743. *Air* was first submitted to the power of the great horseshoe magnet, urged by twenty pairs of Grove's plates in this apparatus (2739.). The fluid moved very slightly outwards, as if a little expansion occurred on putting on the magnetic force, and returned when the force was taken off. This small effect was found afterwards to be due to compression, occasioned by the tendency of the magnetic poles to approximate (2734.).

2744. *Oxygen* presented exactly the same appearances as common air and to the same amount, so that no effect, due to magnetic or diamagnetic action, was here evident, but only that of the compression observed in the case of air (2743.).

2745. *Nitrogen* gave exactly the same results as oxygen and air. Now nitrogen is probably more diamagnetic than hydrogen, and should therefore have given a striking contrast with oxygen, if any positive results were to be obtained.

2746. *Carbonic acid* and nitrous oxide gases yielded the same negative results, and, as I believe, when the apparatus was in an unexceptionable condition.

2747. There is at the Pharmaceutical Society an excellent electro-magnet, of the horseshoe form, similar in arrangement to our own (2247.), but far more powerful, and this through Mr. Redwood I was favoured with the use of, for the repetition of the foregoing experiments at the house of the Society. The iron, which is very soft and good in quality, is a square bar, 5 inches in thickness, and the medium line is 50 inches in length. It has 1500 feet of copper wire, 0·175 of an inch in thickness, coiled round it, and arranged (when I used it) in one continuous length. The moveable terminal pieces for the poles are massive in proportion to the magnet. Eighty pairs of **Grove**'s plates were used to excite this magnet, and as it was found, by preliminary trials, that these were most powerful when arranged as four twenties, with their similar ends connected, they were so used, constituting a battery of twenty pairs of plates, in which each platinum plate was 4 × 9 inches in the immersed part, and therefore presented 72 square inches of surface towards the active zinc.

2748. On repeating the former experiments (2743.) the effect of pressure was again evident, and it was manifest that the magnet itself, though 5 inches in thickness, was a little bent by the mutual attraction of its poles. The effect was very small, because of the unity of the iron core passing through the centre of the experimental gas-chamber (2738.). It was the only effect indicated by the gauge, and was the same for all the gases; and when allowance was made for it, nothing remained to indicate any change in volume of the gas itself.

2749. *Air, oxygen, nitrogen, carbonic acid* and *nitrous oxide* were submitted, in varying order, to the effect of this very powerful magnet, but not the slightest trace of change of bulk in any of them appeared.

2750. I think that the experiments are in every respect sufficient to decide that these gases, whether they are considered as magnetic or diamagnetic bodies, or whether they include bodies of both classes (for oxygen is in striking contrast to the rest), are not affected in volume by the magnetic force, whether in fields of equal power (2737.), or in places where the power is rapidly diminishing. I think this decision very important in relation to the true nature of the magnetic force, either as existing in, or acting upon the particles of bodies; and as in the magnetic field the force exhibits itself, not as a central but as an axial power, so the further distinction of the phenomena, into such as are related to the axial direction (2733.), and such as are related to or include the equatorial direction (2737.), is not unimportant, for they show that the particles do not tend to separate either parallel to the lines of magnetic power, or in a direction perpendicular to these lines. Without the experiments, the mind might have considered it very possible that one of these modes of expansion might have occurred and not the other.

2751. No doubt it is true, that even yet changes in volume in these directions may occur, provided the change in one direction is expansion and in the other contraction, and that these are in amount equal to each other. It was partly in reference to such possible changes (which may be considered as molecular), that the experiments with the ray of light were made (2723. 2729.), and also that in these and other experiments instituted for the purpose, a polarized ray was employed as the examiner; but the results were always negative, when by repetition and care sources of error were removed.

2752. The great differences in the degree of diamagnetic susceptibility and condition which the gases employed in the foregoing experiments possess or can assume, are such as to make one ready to suppose, that if they show no tendency in any case to change in volume under the action of the magnet, so neither would any other gas or vapour do so, but that all the individuals belonging to this great class of bodies would be alike in that respect. In connection with this conclusion I may state, that I have on former occasions, and more lately, endeavoured to ascertain, by the use of very delicate apparatus and powerful electro-magnets, whether any change was produced in the volume of such fluids as water, alcohol and solution of sulphate of iron, but could observe no effect of the kind, and I do not believe in its existence. Still more recently, and in reference to the class of solid bodies, I have submitted iron as a magnetic metal, and bismuth as a diamagnetic body, to the same examination; the metals were employed both in the state of solid cylinders and of filings or fragments. The cylinders were put into glass tubes and the particles into glass bottles; gauges, like those described (2732.), were applied to them, and that part of the containing vessel which was not filled with metal, was occupied, in one set of experiments, by air, and in another by alcohol, yet in no case could the least change in the volume of the iron or bismuth be observed, however powerful the magnetic force to which they were submitted.

2753. One other result of a repulsive force seemed possible even in cases when, according to a former supposition (2751.), the tendency to expand equatorially might be compensated by an equal amount of tendency to contract in the axial direction, namely, that of the production of currents outwards or equatorially, *i. e.* in lines perpendicular to the magnetic axis, where pointed poles or the hour-glass core, already described, were used, and of other currents setting in towards that line along the inclined surfaces of the polar terminations; in some degree like those occurring so powerfully, and traced so readily when flame or hot air is observed in air, or when a stream of one gas is observed in another gas*.

2754. When however the gas occupying the whole of the magnetic field was uniform in nature and alike in temperature, not the slightest trace of such currents as these could be observed. It is not easy to devise unexceptionable tests of such motions, because visible bodies introduced into such a magnetic field to test the movements of the air there, are themselves diamagnetic; and if they form a little isolated cloud, are moved together and away as a diamagnetic body would be; but when the whole field was occupied pretty equally by very light particles of dust or lycopodium, and the magnet in powerful action, no signs of currents in the air were visible. Further, when a faint stream of diffuse cold smoke from a taper spark† was allowed to fall or rise a little on one side of the axial line, it was determined outwards and equatorially; but though it went outwards with the most force when equidistant from the two conical poles, or their representative parts in the double iron core (2738.), still when it was made to pass near to one side, it continued to go outwards and equatorially, even when, from its close vicinity to the iron surface, it had as it were to move

* Philosophical Magazine, 1847, vol. xxxi. pp. 402, 404, 409.

† Ibid, p. 403.

over it; showing that the tendency of the smoke was outwards in *every part* of the magnetic field occupied by air or gas, and that therefore its motion was due to the action of the magnet on it as a diamagnetic, and not to currents of the air, which, if existing, would be inwards in one place or direction, and outwards in another.

2755. When magnetic or diamagnetic fluids were subject to the magnetic force upon a plate of mica over the poles, according to the ingenious arrangement of Plücker, they quickly assumed the different forms correspondent to their nature, but after that there was no further motion or current in them. The cases are no doubt different to those where the whole of the magnetic field is occupied by the same medium; still, as far as it goes, it helps to confirm the conclusion that no currents are formed. On putting the same liquids between the poles in glass cells, no magnetic currents could be observed in them, though fine particles were introduced into the fluids, for the purpose of making such changes of place visible, if they occurred.

2756. So there is no evidence, either by the action on a ray of light (2727. 2729.), or by any expansion or contraction (2750.), or by the production of any currents (2754.), that the magnet exerts any direct power of attraction or repulsion on the particles of the different gases tried, or that they move in the magnetic field, as they are known to do, by any such immediate attraction or repulsion.

¶ ii. *Differential magnetic action.*

2757. Then what is the cause of the diamagnetic change of place? The effect is evidently a differential result, depending upon the *differences* of the two portions or masses of matter occupying the magnetic field, as the air and the streams of other gas in it*, or mercury and the tube of air in it (2407.), or water and the piece of bismuth in it (2301.); and though exhibited only in the action of masses, the latter must no doubt owe their differences to the qualities of the particles composing them. Yet it is to be observed, that no attempt to separate the perfectly mixed particles of very different substances has ever succeeded, though made with most powerful magnets. Oxygen and nitrogen differ exceedingly, yet no appearance of the least degree of separation occurred in very powerful magnetic fields†. In other experiments I have enclosed a dilute solution of sulphate of iron in a tube, and placed the lower end of the tube between the poles of a powerful horseshoe magnet for days together, in a place of perfectly uniform temperature, and yet without the least appearance of any concentration of the solution in that end which might indicate a tendency in the particles to separate.

2758. The diamagnetic phenomena of the gases, when considered as the differential result of the action of volumes of these bodies, may be produced and examined in a very useful manner by the employment of soap-bubbles, as follows:—A glass tube was fitted with a cap, stopcock and bladder, so that any given gas contained in the blad-

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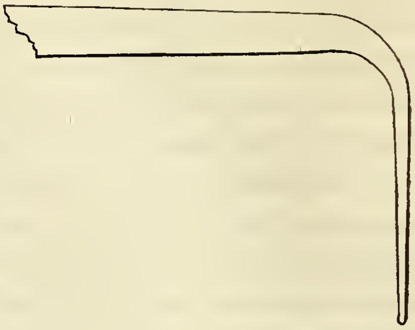
* Philosophical Magazine, 1847, vol. xxxi. p. 409.

† Ibid. p, 416.

Fig. 4.



der might be sent through it, and also with a foot or stand so that it might be placed in any required position. The end of the tube was drawn down, bent at right angles, and cut off straight across at the extremity, being of the size and shape represented in fig 4.

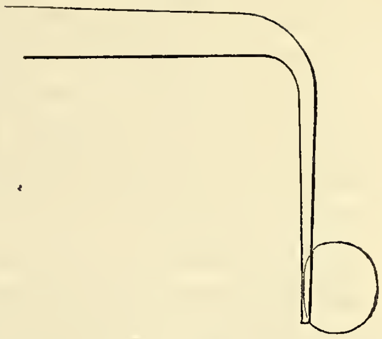
2759. It is easy to blow soap-bubbles at the end of such a tube, of any size up to an inch in diameter, and retain them for the time required by the action of the stopcock. The soapy water should be prepared, when wanted (and not beforehand), by putting a cutting or two of soap into a little cold distilled water, for then bubbles of the thinnest and most equable texture can be blown, which are more mobile than if thicker suds be used, and if a little care be taken, quite permanent enough for every useful experiment. The end of the pipe should be perfectly clean and free from heterogeneous matter (which is often destructive of the bubble), and should be wetted both inside and outside with the soap-water, and *left awhile in it before use.*

2760. If a bubble be blown with the end of the tube downwards, and be half an inch in diameter, it will usually have a little extra water at the bottom, and will hang from the slender extremity of the tube by an attachment so small as to allow it great freedom of motion. Hence it will swing to and fro like a pendulum ; and according as there is more or less water at the bottom, it will vibrate more or less rapidly, will, as a whole, gravitate more or less powerfully, and therefore will retain its perpendicularly dependent position with more or less stability,—circumstances which are very useful in the employment of the bubble as a magnetic or diamagnetic indicator.

2761. The determination of the relative quantity of water which is in or upon the bubble is easily obtained within certain limits. If, after the pipe is dipped in the soap-water, the end be touched with a piece of wood or glass rod, which has also been kept in the soap-water, more or less of the liquid may be removed ; and by observing the height at which the fluid stands by capillary action within the tube, which may be varied between $\frac{1}{20}$th and $\frac{1}{2}$ an inch, it is easy, after a few experimental trials, to observe how much is required to make a bubble charged with a certain amount of water, and how little to give a bubble without any dependent water below ; and then it is just as easy, by arranging the amount of water beforehand, to blow a bubble of any required character. Even when no drop of water is left at the bottom, still a range of thickness or thinness in the film itself can be obtained.

2762. As the bubbles contain less and less of water, so are they rendered more sensitive in their action. They vibrate slower, and are more easily moved by forces applied laterally to them. The diamagnetic effect of the soap-water constituting them is less, and therefore that of the gas contained within them comparatively greater. If the bubble is very thin, the dependent position becomes a position of unstable equilibrium, for any inclination of the tube, or any lateral force, however small, then causes the bubble to pass to one side, and to run up and adhere to the

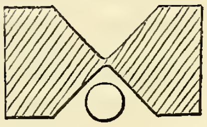
Fig. 5.



side of the tube, fig. 5. The dependent position supplies, in inclosed spaces or atmospheres, an exceedingly delicate indicator; and even when the bubble is on the side of the tube it still forms a very valuable instrument, for it freely moves round the tube as axis; and as it possesses a certain degree of steadiness, it can be held in the magnetic field in any position, and by its motion to or from the axial line, shows very well the magnetic or diamagnetic condition of the gas contained in it in relation to the surrounding air.

2763. If the mouth of the tube be turned upwards, bubbles of the thinnest texture can be blown; but they are then also very unstable in position, and run to the side of the tube; they can be used as indicators, as above (2762.). If the mouth of the tube be made broader, the bubbles, being thin, can be retained standing on the extremity; but as their attachment is larger, so they require more force to move them sideways, and they lose in delicacy of indication.

Fig. 6.



2764. It is convenient, in working with such bubbles, to make them nearly equal in size and thickness for the same set of comparative experiments. I usually employ them about half an inch in diameter. On blowing such a bubble with *air*, in the dependent position, placing it in the angle of the double pole on a level with the axial line (fig. 6), and then putting on the magnetic power, by the use of twenty pair of plates the bubble was deflected outwards from the axial line (or equatorially) with a certain amount of force, and returned to its first position on the interruption of the electric current. The deflection was not great, and being due to the water of the bubble, gave an indication of the amount of that effect, to be used as a correction in experiments with other gases.

2765. *Nitrogen in air.*—A bubble of nitrogen went outwards or equatorially in common air with a force much surpassing the outward tendency of a bubble of air (2764.), in a very striking and illustrative manner. It was often driven up from the end to the side of the tube; and when on the side, if presented inwards, it was driven to the outside of the tube, and however the tube was turned round, kept that position as long as the magnetic force was maintained. This effect is the more striking when it is considered that four-fifths of the air itself is nitrogen gas.

2766. *Oxygen in air.*—The effect was very impressive, the bubble being pulled inwards or towards the axial line sharply and suddenly, exactly as if the oxygen were highly magnetic. The result was expected, being in accordance with the phenomena presented by oxygen and nitrogen in a former investigation of the diamagnetic phenomena of the gases*.

2767. *Nitrous oxide and olefiant gases in air.*—The bubbles went outwards or diamagnetically with a force much greater than that due to the effect of the water of the bubble, proving the relation of these gases to air, and according with the results formerly obtained with streams of these substances†.

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* Philosophical Magazine, 1847, vol. xxxi. pp. 410, 415.

† Ibid. p. 411.

2768. There is no difficulty in applying this method of observation to experiments with gases in atmospheres of other gases than air, provided they be such as do not destroy the bubble; but I do not consume time by detailing the results of such experiments, which accorded perfectly with those before obtained*. The description given is quite sufficient to illustrate the point stated, namely, that the motions of the gases, one in another, when in the magnetic field, is a differential result, and supply sufficient cases for reference hereafter.

2769. The same conclusion, that the effect is a differential result of the masses of matter present in the magnetic field, is also manifest from the consideration of the cases of gaseous, liquid, and solid diamagnetic bodies, advanced in a former part of these Researches (2405–14.); and a conclusion of the same kind, as regards magnetic bodies, may also be drawn from experiments then described (2361–68.).

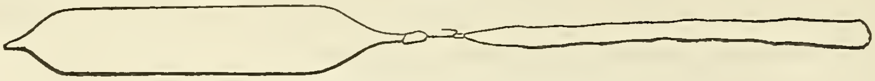
¶ iii. *Magnetic characters of Oxygen, Nitrogen and Space.*

2770. The differential action of two portions of gas, or of any two bodies, may, by a more elaborate method, be examined in a manner far more interesting and important than that just described. The mode of action referred to may even be made the basis of instruments, by which, probably, most important indications and measurements of both magnetic and diamagnetic actions may be obtained, leading to results which are not even as yet contemplated by the imagination.

2771. If two portions of matter, gaseous or liquid, are tied together and placed in a symmetric magnetic field, on opposite sides of the magnetic axis, they will be simultaneously affected. If both are diamagnetic, or less magnetic than the medium occupying the magnetic field, both will tend to go outwards or equatorially; equally if they are alike, but unequally if they differ. The consequence will be, that, if they are placed, in the first instance, equidistant from the magnetic axis, the supervention of the magnetic force will not alter their position, provided they be alike; but if they differ, then their position will be changed; for the most diamagnetic will move outwards equatorially, pulling the least diamagnetic inwards until the two are in such new positions that the forces acting on them are equipoised, and they will assume a position of stable equilibrium. Now the distance through which they will move may be used indirectly, or better still, the force required to restore them to their equidistant position may be employed directly to estimate the tendency each had to go from the magnetic axis; that is, to give their relative diamagnetic intensities.

2772. That I might submit gases to such a method of examination, I selected a piece of very thin and regular flint-glass tube, about $\frac{5}{16}$ths of an inch external diameter, and not more than $\frac{1}{60}$th of an inch in thickness, and drawing at the blowpipe lamp two equable portions of this tube into the shape and size represented, fig. 7, in which the barrel part is $1\frac{1}{2}$ inch long, I filled one with oxygen gas and the other

Fig. 7.



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* Philosophical Magazine, 1847, vol. xxxi. pp. 414, 415.

with nitrogen gas, and then sealed them up hermetically. The end of the prolonged part of each was touched whilst warm with sealing-wax and a thread fastened to it, which thread was tied into a loop, also represented of full size. By these the tubes were to be suspended perpendicularly from a torsion balance, so that the middle of each should, when in place, be on a level with the magnetic axis.

2773. The torsion balance consisted of a bundle of sixty equally stretched cocoon silk fibres, made fast above to a vertical axis carrying a horizontal index and graduated plate, and below to a horizontal lever. A cross bar, about 1½ inch long, was attached to one end of this lever, also in the horizontal plane; and on the extremities of this cross bar, and 8½ inches from the centre of motion, were hung the two tubes of oxygen and nitrogen (2772.), counterbalanced by a weight on the other arm of the horizontal level. The whole was thus so placed and adjusted in relation to the electro-magnet, furnished at the time with the double cone core or keeper (2764.), that the middle part of each tube was level with the middle of the core, and equidistant on each side from it. Under these circumstances, if any motion was given to the balance, so as to make its arm vibrate, the vibrations were made with great slowness, in consequence of the weight of the whole moving arrangement, and the small amount of torsion force in the cocoon silk.

2774. The moment the magnetic force was thrown into action all things changed. The oxygen tube was immediately carried inwards towards the axis, and the nitrogen tube driven outwards on the contrary side. The balance swung beyond its new place of rest and then returned with considerable power, vibrating many times in the period, which before was filled by a single oscillation; and when it had come to its place of rest, or of stable equilibrium, the oxygen tube was about one-eighth of an inch from the iron of the core, and the nitrogen tube four-eighths distant. Ten revolutions of the torsion axis altered only in a slight degree these relative distances.

2775. The actions which determine the mutual self-adjustment of the oxygen and nitrogen, as regards their place in relation to the magnetic axis, are very simple and evident. In the first place, the *glass* of the tubes is more diamagnetic than the surrounding medium or air (2424.), and therefore each tends to move outwards; but being equal in nature and condition to each other, they tend to move with equal force when at equal distances, and at those distances compensate each other. If one be driven inwards, it is subjected to a greater exertion of force by coming into a more intense part of the magnetic field; and the other, being at the same time carried outwards, is for a corresponding reason in a place of less intense action; and therefore, as soon as the constraint is removed, the system returns to its position of stable equilibrium, in which the two bodies are equidistant from the magnetic axis.

2776. The *contents* also of the tubes are subject to the magnetic forces, and as the result shows (2774.), in very different degrees. Either the oxygen tends inwards much more forcibly than the nitrogen, or the nitrogen tends outwards more powerfully than the oxygen; and the difference must exist to a very great degree, for it is such as to carry the glass of the oxygen tube up to a position so near the axis that it could not by itself, or with mere air inside, retain it for a moment without the aid of considerable restraint. The power with which the tubes only would retain their equidistant position, combined with the extent to which they are displaced from this position, shows the great amount of force which this conjoint action of the oxygen and the nitrogen leaves free to be exerted in the one direction, namely, from the oxygen inwards or axially, for though the action be complicated the result is simple. By former experiments, the nitrogen is known to pass equatorially and the oxygen axially in air*, and the nitrogen tube will pass equatorially according to a certain differential force, depending on the flint-glass and the nitrogen on the one hand, and the bulk of air displaced by them on the other. The oxygen tube in like manner will tend to pass axially by a differential force, the amount of which will depend upon the tendency of the oxygen to go axially, of its tube to go equatorially, and of their joint relation to the air they displace. But both the tubes and their contents are by their joint relation to the air and their mechanical connexion so related to each other, that when a force (as of torsion) is employed to restore them to their equidistant position from the magnetic axis, all consideration of the matter of the tubes and of the air as a surrounding medium may be dismissed. The gases within them may be considered as in immediate relation with each other and the magnetic axis, and disembarrassed from all other actions: and the force which may be found needful to place them *equidistant,* is the measure of their magnetic or diamagnetic differences.

2777. Having thus explained the general principles of action, I will not at present go into their application in the construction of a measuring instrument or the results obtained with it, further than is required for the general elucidation of magnetic and diamagnetic bodies, and the determination of the true zero-point (2721. 2722.).

2778. The principles just described enabled me to return to a method of investigation which on a former occasion greatly excited my hopes (2433.), but which seemed then suddenly cut off by want of power. Various bodies, whether considered as magnetic or diamagnetic substances, admit of two modes of treatment, which promise to be exceedingly instructive as regards their properties and their destined purposes in natural operation. A gas may be *heated* or *cooled,* and the effect of temperature, which is known to be very influential†, may now be ascertained without any change in the bulk of the gas; or it may be *rarefied* and *condensed* through a very extensive range, and the effect of this kind of change upon it ascertained independent of temperature or the presence of any other substance. Solids and liquids do not admit of these methods of examination, and do not therefore assist in the determination of the zero-point and of the true distinction of magnetic and diamagnetic bodies in the same manner that the gases do.

2779. It appeared to me that if a gaseous body were magnetic, then its magnetic properties ought to be diminished in proportion as it was rarefied, *i. e.* that equal volumes of such a gas at different pressures ought to be more magnetic, as they are denser; on the other hand, that if a gas were diamagnetic, rarefaction ought to diminish its diamagnetic character, until, when reduced to the condition of a vacuum, it should disappear. In other words, if two opposed portions of the same magnetic gas, one rarer than the other, were subjected at once to the magnetic force, the *denser* ought to approach the axial line, or be drawn into the place of most intense action ; whereas if two similarly opposed portions of a diamagnetic gas were subjected to the magnetic action, the more expanded or *rarer* gas ought to go inwards to the place of strongest action.

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* Philosophical Magazine, 1847, vol. xxxi. p. 409.

† Ibid. pp. 406, 417.

Fig. 8.

2780. Several bulbs of oxygen (fig. 8), similar in arrangement to those already described (2772.), and very nearly alike in size, were prepared and hermetically sealed, after that the quantity of gas within them had been reduced to a certain degree by the air-pump. The first contained the gas at the pressure of one atmosphere ; the second had the gas at half an atmosphere, or 15 inches of mercury ; the third contained gas at the pressure of 10 inches of mercury ; and the fourth, after being filled with oxygen, was reduced to as good a vacuum as an excellent air-pump could effect. When the first of these was compared with the other three, the effect was most striking ; opposed to the half atmosphere, it went towards the axis, driving the expanded portion away ; when in relation to the one-third atmosphere, it went inwards or axially with still more power ; and when opposed to the oxygen vacuum, it took its place as close to the iron core as in the former case, when contrasted with nitrogen (2774.) ; and it was manifest that the diamagnetic power of the glass tube which inclosed it (2775.), was the only thing which prevented the oxygen from pressing against the iron core occupying the centre of the magnetic field.

2781. On experimenting with the other tubes exactly the same result was obtained. Thus the tube with one-third of an atmosphere, in association with the vacuum tube, went inwards, driving the other outwards, *i. e.* it was more magnetic than the vacuum ; but in association with the one-half atmosphere tube it went outwards, whilst the denser gas passed inwards. Any one of the tubes, if associated with another having a rarer atmosphere, passed inwards or magnetically, whilst if associated with others having denser atmospheres it passed outwards, being driven off by the superior magnetic force of the denser gas. As far as I could ascertain in these preliminary forms of experiment, the tendency inwards or axially appeared to be in proportion to the density of the gas ; but the exact measurement of these forces will be given hereafter.

2782. Thus oxygen appears to be a very magnetic substance, for it passes axially, or from weaker to stronger places of force, with considerable power ; a conclusion in accordance with the result of former observations*. Moreover it passes more powerfully when dense than when rare, its tendency inwards being apparently in proportion to its density. Hence, as the oxygen is removed, the magnetic force disappears with it, until when a vacuum is obtained, little or no trace of attraction or inward force remains. No doubt it may be said that dense oxygen is less diamagnetic than rare oxygen, or a vacuum. This however would imply, that the acting force of a substance, as the oxygen, could increase in proportion as the quantity of the substance diminished, which is not, I think, a philosophical assumption; and besides that, other reasons will soon appear to show that the magnetic condition which disappears as the oxygen is removed, belongs to, and is dependent upon that substance, and that oxygen is therefore a truly magnetic body.

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* Philosophical Magazine, 1847, vol. xxxi. pp. 410, 415.

2783. *Nitrogen*, being the other and larger part of the atmosphere, was then subjected to experiment, and three tubes, one containing the gas at a pressure of 30 inches of mercury, another with the gas at the pressure of 15 inches, and the third reduced as nearly as it could be to a vacuum, were prepared (2780.). When these were compared one with another in the magnetic field, they were found to be so nearly alike as not to be distinguishable from each other, *i. e.* they remained equidistant from the magnetic axis. I do not mean to imply that nitrogen at these different pressures is absolutely the same bulk for bulk (an instrument now under construction will enable me hereafter to compare and measure with infinitely greater accuracy, and to ascertain these points); but as compared with oxygen, the great and extraordinary differences produced by rarefaction there, have no corresponding differences here. If there are any, they are insensible at present, and may, for the chief purpose of this paper and the determination of the zero-point between magnetics and diamagnetics, be taken as nothing.

2784. Nitrogen therefore appears to be neither magnetic nor diamagnetic; if it were either, it could not but fall in its specific condition as it was rarefied; as it is, it is equivalent to a vacuum. If a given space be considered as a vacuum, into which oxygen or nitrogen is to be gradually introduced, as oxygen is added the space becomes more and more magnetic, *i. e.* more competent to admit of the kind of action distinguished by that word; but the corresponding gradual addition of nitrogen to an empty space produces no effect of that kind, or the contrary, and the nitrogen is therefore neither magnetic nor diamagnetic, but like space itself.

2785. As yet I have found no gas, which, being on the diamagnetic side of zero, can at all compare with oxygen in the range of effect produced by rarefaction. For the present, I may mention olefiant gas and cyanogen as substances which appear to proceed inwards, or towards the axial line, as they are more rarefied. They are therefore not merely at zero, but are in opposition to oxygen and are diamagnetic bodies. But if we want a body that is strongly and undeniably diamagnetic, and which, being added to or introduced into space, will make it diamagnetic, as oxygen renders it magnetic, then flint glass or phosphorus presents us with such a substance. When these bodies are made into forms similar to the volumes of nitrogen, or the vacua in size and shape, and are compared with them on the torsion balance, they pass outwards with much force; and it is probably the great diamagnetic force of the glass of the tubes that prevents the effect of rarefaction from being more evident in olefiant and other gases.

2786. When a tube has been filled with a particular gas, then exhausted as much as possible, and sealed up hermetically, it may be considered as inclosing what is commonly called a vacuum. I have prepared many such vacua, and may be permitted to distinguish them by the name of the gas, traces of which still remain. In comparing these vacua in the magnetic field (2773.), they appeared to me to be in all respects alike; the oxygen vacuum was not more magnetic than the hydrogen, nitrogen, or olefiant vacuum. Their differences, if any, were far smaller than the differences which could be produced by the variations of size and other conditions of the glass bulbs, and can only be made manifest by the means hereafter to be used (2783.); and I am fully persuaded that they will ultimately be nearly alike, ranging close *up to and about a perfect* vacuum.

2787. Before determining the place of zero amongst magnetic and diamagnetic bodies, we have to consider the true character and relation of *space* free from any material substance. Though one cannot procure a space perfectly free from matter, one can make a close approximation to it in a carefully prepared Torricellian vacuum. Perhaps it is hardly necessary for me to state, that I find both iron and bismuth in such vacua perfectly obedient to the magnet. From such experiments, and also from general observations and knowledge, it seems manifest that the lines of magnetic force (2149.) can traverse pure space, just as gravitating force does, and as static electrical forces do (1616.); and therefore space has a magnetic relation of its own, and one that we shall probably find hereafter to be of the utmost importance in natural phenomena. But this character of space is not of the same kind as that which, in relation to matter, we endeavour to express by the terms magnetic and diamagnetic. To confuse them together would be to confound space with matter, and to trouble all the conceptions by which we endeavour to understand and work out a progressively clearer view of the mode of action and laws of natural forces. It would be as if, in gravitation or electric forces (1613.), one were to confound the particles acting on each other with the space across which they are acting, and would, I think, shut the door to advancement. Mere space cannot act as matter acts, even though the utmost latitude be allowed to the hypothesis of an ether; and admitting that hypothesis, it would be a large additional assumption to suppose that the lines of magnetic force are vibrations carried on by it (2591.); whilst as yet, we have no proof or indication that time is required for their propagation, or in what respect they may in general character assimilate to, or differ from, the respective lines of gravitating, luminiferous, or electric forces.

2788. Neither can space be supposed to have those circular currents round points diffused through it, which AMPÈRE's theory assumes to exist around the particles of ordinary magnetic matter, and which I had for a moment supposed might exist in the contrary direction round the particles of diamagnetic matter (2429. 2640. &c.). The imagination, restrained by philosophical considerations, fails to find anything in pure space about which the currents could circulate, or to which they could by any association be attached; and the difficulty, if already not immeasurable, would be still greater to those, if there be any, who, assuming that magnetic and diamagnetic bodies are alike in nature, must assume that there are like currents in both; for it does not seem possible to add (for instance) phosphorus having such a magnetic constitution to space, supposed to be of a similar constitution, and yet to have as a result a diminution of the magnetic powers of the space.

2789. As space therefore comports itself independently of matter, and after another manner, the different varieties of matter must, in relation to their respective qualities, be considered amongst themselves. Those which produce no effect when added to space, appear to me to be neutral or to stand at zero. Those which bring with them an effect of one kind will be on the one side of zero, and those which produce an effect of the contrary kind will be on the other side of zero; by this division they constitute the two subdivisions of magnetic and diamagnetic bodies. The law which I formerly ventured to give (2267. 2418.), still expresses accurately their relations; for in an absolute vacuum or free space, a magnetic body tends from weaker to stronger places of magnetic action, and a diamagnetic body under similar conditions from stronger to weaker places of action.

2790. Now that the *true zero* is obtained, and the great variety of material substances satisfactorily divided into two general classes, it appears to me that we want another name for the magnetic class, that we may avoid confusion. The word *magnetic* ought to be general, and include *all* the phenomena and effects produced by the power. But then a word for the subdivision, opposed to the diamagnetic class, is necessary. As the language of this branch of science may soon require general and careful changes, I, assisted by a kind friend, have thought that a word not selected with particular care might be provisionally useful; and as the magnetism of iron, nickel and cobalt, when in the magnetic field, is like that of the earth as a whole, so that when rendered active they place themselves parallel to its axis or lines of magnetic force, I have supposed that they and their similars (including oxygen now) might be called paramagnetic bodies, giving the following division:—

$$\text{Magnetic}\begin{cases}\text{Paramagnetic.}\\ \text{Diamagnetic.}\end{cases}$$

If the attempt to facilitate expression be not accepted, I hope it will be excused.

2791. From the presence of oxygen in the air, the latter is, as a whole, a magnetic medium of no small power. Hence all the comparative experiments on the diamagnetic condition of other gases, made by passing streams of them through it and through each other*, require a correction, which occasionally may place some of these bodies on the paramagnetic side of zero. Even solid and fluid substances may be thus affected; and the preliminary list, which I formerly gave (2424.), will need alteration in this respect. I hope soon however to have the means of ascertaining, not only the place of bodies, but also their relative degrees of force, at the same and at different temperatures, with a degree of accuracy that will serve great purposes in the further development of this branch of science.

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* Philosophical Magazine, 1847, vol. xxxi. pp. 407, 420, &c. &c.

2792. Amongst the gases hitherto examined there is nothing that compares with oxygen. The following are comparatively indifferent by the side of it:—chlorine and bromine vapour, cyanogen, nitrogen, hydrogen, carbonic acid, carbonic oxide, olefiant gas, nitrous oxide, nitric oxide, nitrous acid vapour, muriatic acid, sulphurous acid, hydriodic acid, ammonia, sulphuretted hydrogen, coal-gas, ether vapour and sulphuret of carbon vapour; for though some, as olefiant and cyanogen gases, appear to be a little diamagnetic, and others, as nitrous oxide and nitric oxide, are magnetic, yet their effects disappear in comparison with the results produced by oxygen.

2793. I hope to give the correct expression of the paramagnetic force of oxygen (2783.) hereafter, in the meantime I am tempted to give one or two rough illustrations of its degree in this place, in addition to the former one (2774.). The capacity of the oxygen bulb, containing one atmosphere, is not quite 0·34 of a cubic inch, and the weight therefore of the oxygen within 0·117 of a grain. I endeavoured to compare this quantity in the first place with soft iron, and therefore attached a portion of that metal, having one-tenth of this weight or 0·012 of a grain, to a fine platina wire fixed into one end of a vessel, corresponding in size to that containing the oxygen, so as to bring the iron into the middle, and then the bulb was exhausted and hermetically sealed. Being now opposed to the oxygen tube in the magnetic field, it was found, as expected, far to surpass the oxygen in magnetic power. As it was inconvenient further to reduce the iron or to enlarge the oxygen, another magnetic substance was employed for the comparison.

2794. One hundred grains of clean, good, crystallized protosulphate of iron were dissolved in distilled water, and diluted until a glass bulb, of nearly the same size as the oxygen bulb when filled with the solution, was equal to the oxygen bulb in force, and stood equidistant from the axial line, as far as I could judge by the present modes of observation. When the solution had this strength, it occupied the bulk of $17\frac{1}{2}$ cubic inches. As the bulk of the oxygen is only 0·34 of a cubic inch (2793.), that volume of this solution would contain very nearly two grains of crystallized sulphate of iron, equivalent to 0·4 of a grain of metallic iron; so that, bulk for bulk, oxygen is equally magnetic with a solution of sulphate of iron in water containing seventeen times the weight of the oxygen in crystallized protosulphate of iron, or 3·4 times its weight of metallic iron in that state of combination.

2795. Again, the oxygen tubes, containing respectively one atmosphere and a vacuum (2780.), were adjusted about an inch apart, and placed on each side of the magnetic axis, and the force of the magnet developed. The oxygen of course approached the magnetic axis, and the vacuum passed equatorially. A slender glass filament, about 6 inches in length, had been drawn out at the lamp and fixed to a foot; and the end of this filament was then employed to press back the oxygen tube into its original place, and render it equidistant from the magnetic axis with the vacuum tube. In this position the two tubes would, as respects the glass, neutralize each other (2775.); and considering the vacuum as zero, the oxygen alone may be considered as active, and the force required to hold it out may be looked upon as the force with which the oxygen, at that distance of half an inch, tended to go to the magnetic axis. The deflection of the glass filament or spring, at the place where the oxygen tube was held by it, was rather more than 1 inch from its position when relieved from the pressure of the tube. Being taken away, it was set up in the horizontal position (after being turned 90° on its axis, so that the flexure might be in the same direction, relative to the filament, as before); and the position of the end being marked, weights were put on it at the place of former contact with the oxygen tube, until they produced the same amount of deflection as before. It required rather more than the tenth of a grain to produce this effect; and this, considering that the whole oxygen only weighed 0·117 of a grain, and that no part of it was nearer than half an inch, whilst the average distance of the mass was above an inch from the magnetic axis, gives a high expression for the magnetic power.

2796. It is hardly necessary for me to say here that this oxygen cannot exist in the atmosphere, exerting such a remarkable and high amount of magnetic force, without having a most important influence on the disposition of the magnetism of the earth as a planet, especially if it be remembered that its magnetic condition is greatly altered by variations in its density (2781.) and by variations in its temperature*. I think I see here the real cause of many of the variations of that force, which have been, and are now, so carefully watched on different parts of the surface of the globe. The daily variation and the annual variation both seem likely to come under it; also very many of the irregular continual variations which the photographic process of record renders so beautifully manifest. If such expectations be confirmed, and the influence of the atmosphere be found able to produce results like these, then we shall probably find a new relation between the aurora borealis and the magnetism of the earth, namely, a relation established, more or less, through the air itself in connexion with the space above it; and even magnetic relations and variations which are not as yet suspected, may be suggested and rendered manifest and measurable, in the further development of what I will venture to call *Atmospheric Magnetism* (2847. &c.). I may be over-sanguine in these expectations, but as yet I am sustained in them by the apparent reality, simplicity and sufficiency of the cause assumed, as it at present appears to my mind. As soon as I have sufficiently submitted these views to a close consideration and the test of accordance with observation, and where applicable with experiments also, I will do myself the honour to bring them before the Royal Society.

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* Philosophical Magazine, 1847, vol. xxxi. p. 417.

Royal Institution, August 2, 1850.

III. *Experimental Researches in Electricity.—Twenty-sixth Series.* By Michael Faraday, *Esq., D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Ord. Boruss. Pour le Mérite, Eq., Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, Munich, Bruxelles, Vienna, Bologna, &c. &c.*

Received October 9*,—Read November 28, 1850.

§ 32. *Magnetic conducting power.* § 33. *Atmospheric magnetism.*

¶ i. *Magnetic conduction.* ¶ ii. *Conduction polarity.* ¶ iii. *Magnecrystallic conduction.* § 33. *Atmospheric magnetism.* ¶ i. *General Principles..*

¶ i. *Magnetic conduction.*

2797. THE remarkable results given in a former series of these researches (2757. &c.) respecting the powerful tendency of certain gaseous substances to proceed either to or from the central line of magnetic force, according to their relation to other substances present at the same time, and yet the absence of all condensation or expansion of these bodies (2756.) which might be supposed to be consequent on such an amount of attractive or repulsive force as would be thought needful to produce this tendency and determination to particular places, have, upon consideration, led me to the idea, that if bodies possess different degrees of *conducting power* for magnetism, that difference may account for all the phenomena; and, further, that if such an idea be considered, it may assist in developing the nature of magnetic force. I shall therefore venture to think and speak freely on this matter for a while, for the purpose of drawing others into a consideration of the subject; though I run the risk, in doing so, of falling into error through imperfect experiments and reasoning. As yet, however, I only state the case hypothetically, and use the phrase *conducting power* as a general expression of the capability which bodies may possess of affecting the transmission of magnetic force; implying nothing as to how the process of conduction is carried on. Thus limited in sense, the phrase may be very useful, enabling us to take, for a time, a connected, consistent and general view of a large class of phenomena; may serve as a standard of meaning amongst them, and yet need not necessarily involve any error, inasmuch as whatever may be the principles and condition of conduction, the phenomena dependent on it must consist among themselves.

2798. If a medium having a certain conducting power occupy the magnetic field, and then a portion of another medium or substance be placed in the field having a greater conducting power, the latter will tend to draw up towards the place of greatest force, displacing the former. Such at least is the case with bodies that are freely magnetic, as iron, nickel, cobalt and their combinations (2357. 2363. 2367. &c.), and such a result is in analogy with the phenomena produced by electric induction. If a portion of still higher conducting power be brought into play, it will approach the axial line and displace that which had just gone there; so that a body having a certain amount of conducting power, will appear as if attracted in a medium of weaker power, and as if repelled in a medium of stronger power by this differential kind of action (2367. 2414.).

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* Revised by the author and returned by him November 12, 1850.

2799. At the same time that this idea of conduction will thus account for the place which a given substance would take up, as of oxygen in the axial line if in nitrogen, or of nitrogen at a distance if in oxygen, it also harmonizes with the fact, that there are no currents induced in a single gas occupying the magnetic field (2754.), for any one particle can then conduct as well as any other, and therefore will keep its place; and it also agrees, I think, with the unchangeability of volume (2750.).

2800. In reference to the latter point, we have to consider that the force which urges such a body as oxygen towards the middle of the field, is not a central force like gravitation, or the mutual attraction of a set of particles for each other; but an axial force, which, being very different in character in the direction of the axis and of the radii, may, and must produce its effect in a very different manner to a purely central force. That these differences exist, is manifest by the action of transparent bodies, when in the magnetic field, upon a ray of light; and also by the ordinary action of magnetic bodies: and hence, perhaps, the reason, that when oxygen is drawn into the middle of the field, in consequence of its conducting power, still its particles are not compressed together (2721.) by a force that otherwise would seem equal to that effect (2766.).

2801. So when two separate portions of oxygen or nitrogen are in the magnetic field, the one passes inwards and the other outwards, without any contraction or expansion of their relative volumes; and the result is differential, the two bodies being in *relation to and dependence on* each other, by being simultaneously related to the lines of magnetic force which pass conjointly through them both, or through them, and the medium in which they are conjointly immersed.

2802. I have already said, in reference to the transference onwards of magnetic force (2787.), that pure space or a vacuum permits that transference, independent of any function that can be considered as of the same nature as the conducting power of matter; and in a manner more analogous to that in which the lines of gravitating force, or of static electric force, pass across mere space. Then as respects those bodies which, like oxygen, facilitate the transmission of this power more or less, they class together as magnetic or paramagnetic substances (2790.); and those bodies, which, like olefiant gas or phosphorus, give more or less obstruction, may be arranged together as the diamagnetic class. Perhaps it is not correct to express both these qualities by the term *conduction*; but in the present state of the subject, and under the reservation already made (2797.), the phrase may I think be employed conveniently without introducing confusion.

2803. If such be a correct general view of the nature and differences of paramagnetic and diamagnetic substances, then the internal processes by which they perform their functions can hardly be the same, though they might be similar. Thus they *may* have circular electric currents in opposite directions, but their distinction can scarcely be supposed to depend upon the difference of force of currents in the *same* direction. If the view be correct also, though the results obtained when two bodies are simultaneously present in the magnetic field may be considered as differential (2770. 2768.) even though one of them be the general medium, yet the consequence of the presence of conducting power in matter renders a *single* body, when in space, subject to the magnetic force; and the result is, that when a paramagnetic substance is in a magnetic field of unequal force, it tends to proceed from weaker to stronger places of action, or is *attracted*; and when a diamagnetic body is similarly circumstanced, it tends to go from stronger to weaker places of action, or is *repelled* (2756.).

2804. Matter, when its powers are under consideration, may, as to its quantity, be considered either by weight or by volume. In the present case, where the effects produced have an immediate reference to mere space (2787. 2802.), it seems proper that the volume should be considered as the representation, and that in comparing one substance with another, equal volumes should be employed to give correct results. No other method could be used with the differential system of observation (2772. 2780.).

2805. Some experimental evidence, other than those of change of situation, of the existence of this conducting power, by differences in which, I am endeavouring to account for the peculiar characteristics of paramagnetic and diamagnetic bodies, may well be expected. This evidence exists; but as certain considerations connected with polarity preclude me from calling too freely upon iron, cobalt, or nickel (2832.) for illustrations, and as in other bodies which are paramagnetic, as well as in those that are diamagnetic, the effects are very weak, they will be better comprehended after some further general consideration of the subject (2843.).

2806. I will now endeavour to consider what the influence is which paramagnetic and diamagnetic bodies, viewed as conductors (2797.), exert upon the lines of force in a magnetic field. Any portion of space traversed by lines of magnetic power, may be taken as such a field, and there is probably no space without them. The condition of the field may vary in intensity of power, from place to place, either along the lines or across them; but it will be better to assume for the present consideration a field of equal force throughout, and I have formerly described how this may, for a certain limited space, be produced (2465.). In such a field the power does not vary either along or across the lines, but the distinction of direction is as great and important as ever, and has been already marked and expressed by the term axial and equatorial, according as it is either parallel or transverse to the magnetic axis.

Fig. 1.

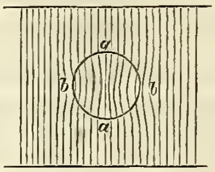
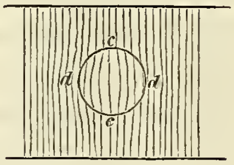


Fig. 2.



2807. When a paramagnetic conductor, as for instance, a sphere of oxygen, is introduced into such a magnetic field, considered previously as free from matter, it will cause a concentration of the lines of force on and through it, so that the space occupied by it transmits more magnetic power than before (fig. 1). If, on the other hand, a sphere of diamagnetic matter be placed in a similar field, it will cause a divergence or opening out of the lines in the equatorial direction (fig. 2); and less magnetic power will be transmitted through the space it occupies than if it were away.

2808. In this manner these two bodies will be found to affect, *first* the *direction* of the lines of force, not only within the space occupied by themselves, but also in the neighbouring space, into which the lines passing through them are prolonged; and this change in the course of the lines will be in the contrary direction for the two cases.

2809. *Secondly*, they will affect the *amount* of force in any particular part of the space within or near them; for as every section across the line of such a magnetic field must be definite in amount of force, and be in that respect the same as every other section, so it is impossible to cause a concentration within the sphere of oxygen (fig. 1) without causing also a simultaneous concentration in the parts axially situated as *a a* outside of it, and a corresponding diminution in the parts equatorially placed, *b b*. On the other hand, the diamagnetic body (fig. 2) will cause diminution of the magnetic force in the parts of space axially placed in respect of it, *c c*, and concentration in the near equatorial parts, *d d*. If the magnetic field be considered as limited in its extent by the walls of iron forming the faces of opposed poles (2465.), then even the distribution of the magnetism within the iron itself will be affected by the presence of the paramagnetic or diamagnetic bodies; and this will happen to a very large extent indeed, when, from among the paramagnetic class, such substances as iron, nickel or cobalt are selected.

2810. The influence of this disturbance of the forces upon the place and position of either a paramagnetic or a diamagnetic body placed within the magnetic field, is readily deduced upon consideration and easily made manifest by experiment. A small sphere of iron placed within a field of equal magnetic power, bounded by the iron poles, has a position of unstable equilibrium, equidistant from the iron surfaces, and at such time a great concentration of force takes place through it, and at the iron faces opposite to it, and through the intervening axial spaces. If the sphere be on either side of the middle distance, it flies to the nearest iron surface, and then can determine the greatest amount of magnetic force to or upon the axial lines which pass through it.

2811. If the iron be a spheroid, then its greatest diameter points axially, whether it be in the position of unstable equilibrium, nearer to or in contact with the iron walls of the field. As the circumstances are now more favourable for the concentration of force in the axial line passing through the body than before, so this result can be produced by much weaker paramagnetics than iron, and I have no doubt could easily be produced by a vessel of oxygen or nitric oxide gas (2782. 2792.). It now becomes indeed a form, though not the best, of that experiment by which the magnetic condition of bodies is considered as most sensitively tested.

2812. The relative deficiency of power in diamagnetic bodies renders any attempt to obtain the converse phenomena to those of iron somewhat difficult; in order therefore to exalt the conditions, I used a saturated solution of protosulphate of iron in the magnetic field; by this means I strengthened the lines of power passing across it, without disturbing its equality in the parts employed, or introducing any error into the principle of the experiment, and then used bismuth as the diamagnetic body. A cylinder of this substance, suspended vertically, tended well towards the middle distance, finding its place of stable equilibrium in the spot where the paramagnetic body had unstable equilibrium. When the cylinder was suspended horizontally, then the direction it took was equatorial; and this effect also was very clear and distinct.

2813. These relative and reverse positions of paramagnetic and diamagnetic bodies, in a field of equal magnetic force, accord well with their known relations to each other, and with the kind of action already laid down in principle (2807.) as that which they exert on the magnetic power to which they are subjected. One may retain them in the mind by conceiving that if a liquid sphere of a paramagnetic conductor were in the place of action, and then the magnetic force developed, it would change in form and be prolonged axially, becoming an oblong spheroid; whereas if such a sphere of diamagnetic matter were placed there, it would be extended in the equatorial direction and become an oblate spheroid.

2814. The *mutual action* of two portions of paramagnetic matter, when they are both in such a field of equal magnetic force, may be anticipated from the principles (2807. 2830.), or from the corresponding facts, which are generally known. Two spheres of iron, if retained in the same equatorial plane, repel each other strongly; but as they are allowed to depart out of that plane, they first lose their mutual repulsive force and then attract each other, and that they do most powerfully when in an axial direction.

2815. With diamagnetic bodies the mutual action is more difficult to determine, because of the comparative lowness of their condition. I therefore resorted to the expedient, before described, of using a saturated solution of protosulphate of iron as the medium occupying the field of equal magnetic force, and employing two cylinders of phosphorus, about an inch long and half an inch in diameter, as the diamagnetic bodies. One of these was suspended at the end of a lever, which was itself suspended by cocoon-silk, so as to have extremely free motion, and the adjustments were such, that when the phosphorus cylinder was in the middle of the magnetic field, it was free to move equatorially or across the lines of magnetic force; it however had *no tendency* to do so under the influence of the magnetic force. The other cylinder was attached to a copper wire handle, and could be placed in a fixed position on either side of the former cylinder; it was therefore adjusted close by the side of it, and the two retained together until all disturbance from motion of the fluid or of the air had ceased; then the retaining body was removed, the two phosphorus cylinders still keeping their places; finally, the magnetic power was brought into action, and immediately the moveable cylinder separated slowly from the fixed one and passed to a distance. If brought back again whilst the magnet was active, when left at liberty it receded; but if restored to close vicinity, when the magnetic force was away, it retained that situation. The effect took place either in the one direction or the other, according as the fixed cylinder was on this or that side of the moving one; but the motion was in both cases across the lines of magnetic force, and was indeed mechanically and purposely limited to that direction by the mode of suspension. When two bismuth balls were placed, in respect of each other, in the direction of the magnetic axis, so that one might move, but only in the direction of that axis, its place was not sensibly affected by the other; the tendency of the free one to go to the middle of the field (2812.) overpowered any other tendency that might really exist.

2816. Thus two diamagnetic bodies, when in the magnetic field, do truly affect each other; but the result is not opposed in its direction to that of paramagnetic bodies, being in both cases a separation of the substances from each other.

2817. The comparison of the action of para- and diamagnetic bodies on each other, was completed by using water as the medium in a field of equal magnetic force, and suspending a piece of phosphorus from the torsion balance. When the magnetic power was on, this phosphorus was repelled equatorially, as before, by another piece of phosphorus, but it was attracted by a tube filled with a saturated solution of protosulphate of iron; so paramagnetic and diamagnetic bodies attract each other equatorially in a mean medium, but each repels bodies of its own kind (2831.).

¶ ii. *Conduction polarity.*

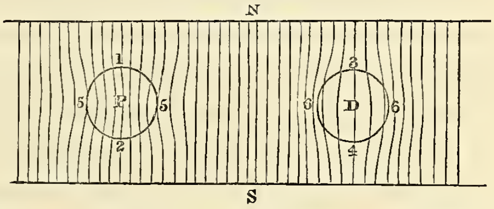
2818. Having thus considered briefly the effects which the disturbance of the lines of force, by the presence of paramagnetic and diamagnetic bodies, is competent to produce (2807. &c.), I will ask attention to that which may be considered as their polarity: not wishing by the term to indicate any internal condition of the substances or their particles, but the condition of the mass as a whole, in respect of the state into which it is brought by its own disturbance of the lines of magnetic force; and that, both in regard to its condition with respect to other bodies similarly affected; and also in regard to differences existing in different parts of its own mass. Such a condition concerns what may be called conduction polarity. Bodies in free space, when under magnetic action, will possess it in its simplest condition; but bodies immersed in other media will also possess it under more complicated forms, and its amount may then be varied, being reversed or increased, or diminished to a very large extent.

2819. Taking the simplest case of paramagnetic polarity, or that presented in fig. 1 (2807.), it consists in a convergence of the lines of magnetic force on to two opposed parts of the body, which are to each other in the direction of the magnetic axis. The difference in character of the two poles at these parts is very great, being that which is due to the known difference of quality in the two opposite directions of the line of magnetic force. Whether polar attraction or repulsion exists amongst paramagnetic bodies, when they present mere cases of conduction (as oxygen, for instance), is not yet certain (2827.), but it probably does; and if so, will doubtless be consistent with the attraction and repulsion of *magnets* having correspondent poles.

2820. When we consider the conduction polarity of a diamagnetic body, matters appear altogether different. It has not a polarity like that of a paramagnetic substance, or one the mere reverse (in name or direction of the lines of force) of such a substance, as I, Weber and others have at times assumed (2640.), but a state of its own altogether special. Its polarity consists of a divergence of the lines of power on to, or a convergence from the parts, which being opposite, are in the direction of the magnetic axis; so that these poles, having the *same* general and opposite relations to each other, which correspond to the differences in the poles of paramagnetic bodies, have still, under the circumstances, that striking contrast and difference from the polarity of the latter bodies which is given by convergence and divergence of the lines of force.

2821. Let fig. 3 represent a limited magnetic field with a paramagnetic body P, and a diamagnetic body, D, in it, and let N and S represent the two walls of iron associated with the magnet (2465.) which form its boundary, we shall then be able to obtain a clear idea of the direction of the lines of magnetic force in the field. Now the two bodies, P and D, cannot be represented by supposing merely that they have the same polarities in opposite directions. The 1 polarity of P is importantly unlike the 3 polarity of D; but if D be considered as having the reverse polarities of P, then the 1 polarity of P should be like the 4 polarity of D, whereas it is more unlike to that than to the 3 polarity of D, or even to its own 2 polarity.

Fig. 3.



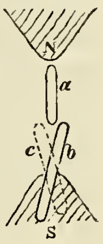
2822. There are therefore two essential differences in the nature of the polarities dependent on conduction, the difference in the direction of the lines of force abutting on the polar surfaces, when the comparison is with a magnet reversed, and the difference of convergence and divergence of these lines, when compared with a magnet not reversed; and hence a diamagnetic body is not in that condition of polarity which may be represented by turning a paramagnetic body end for end, while it retains its magnetic state.

2823. Diamagnetic bodies in media more diamagnetic than themselves, would have the polar condition of paramagnetic bodies (2819.); and in like manner paramagnetic conductors in media more paramagnetic than themselves, would have the polarity of diamagnetic bodies.

2824. Besides these differences the bodies must have an equatorial condition, which, in the two classes of conductors, would be able to produce corresponding effects. The whole of the equatorial part of P (fig. 3) is alike in relation to the body P, or to the lines of force in the surrounding space; and there is a like correspondence in the equatorial parts of D, either to itself or to space; but these parts in P or in D differ in intensity of power one from the other, and both from the general intensity of the space. Such equatorial conditions must, I think, exist as a consequence of the definite character of any given section of the magnetic field (2809.).

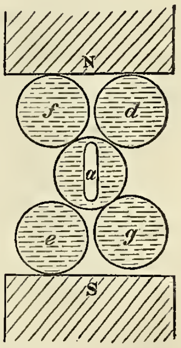
2825. Though the experimental results of these polarities are not absent, still they are not very evident or capable of being embodied in many striking forms; and that because of the extreme weakness of the forces brought into play, as compared with those larger forces exhibited in the mutual action of magnets. Hence it is, that the many attempts to show a polarity in bismuth have either failed, or other phenomena have been mistaken for those properly referable to such a cause. The highest, and therefore the most delicate, test of polarity we possess, is in the subjection of the polar body to the line of direction of magnetic forces of a very high degree, when developed around it; and hence it is, that the pointing of a substance between the poles of a powerful magnet is continually referred to for such a purpose. It would be, and is utterly in vain to look for any mutual action between the poles of two weak paramagnetic or diamagnetic conductors in many cases, when the action of these same poles is abundantly manifest in their relation to the almost infinitely stronger poles of a powerful horseshoe or electro-magnet.

Fig. 4.



2826. I took a tube *a* (fig. 4), filled with a saturated solution of sulphate of cobalt, and suspended it between the poles of the great electro-magnet; it set readily and well. Another tube, *b*, was then filled with a saturated solution of sulphate of iron, and being associated with the S pole of the magnet, was brought near the cobalt tube in the manner shown, but not the slightest effect on the position of *a* was observable. The tube *b* was changed into the position *c*, to double any effect that might be present, but no trace of mutual action between the poles of *a* and *b* was visible (2819.).

Fig. 5.



2827. To increase the effect, the magnetic solution tube was suspended in water, as a good diamagnetic medium, between flat-faced poles (fig. 5). It pointed well. Two bottles of saturated solution of sulphate of iron were placed at *d* and *e*, but they did not alter the position of *a*; being removed into the positions *f* and *g*, neither was any sensible alteration of the position of *a* produced. I made the same kind of experiment with an air-tube in water, in which case it points axially (2406.), with the same negative result. I do not mean to assert that there was absolutely no effect produced in these cases (2819.); but if any, it must have been inappreciably small, and shows how unfit such means are to compare with those which are supplied by the pointing of a body when under the influence of powerful magnets. If polarity cannot be found by these methods in paramagnetic bodies so strongly influential as saturated solution of iron, nickel or cobalt, it can hardly be expected to manifest itself by analogous actions in the much weaker cases of diamagnetic substances.

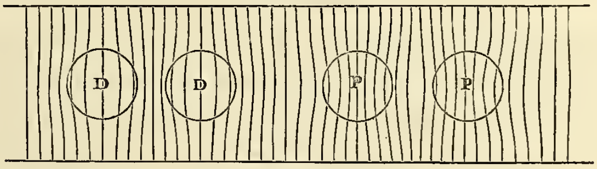
2828. When a spherical paramagnetic conductor is placed midway in a field of equal magnetic force, it occupies a place of unstable equilibrium, from which, if it be displaced ever so little, it will continue to move until it has gained the iron boundary walls of the field (2465. 2810.); this is a consequence of its particular polar condition. If the sphere were free to change its form, it would elongate in the direction of the magnetic axis; or if it were a solid of an elongated form, it would point axially, both consequences of its polar condition (2811.).

2829. So also in the case of diamagnetic bodies, their peculiar condition of polarity is shown by corresponding facts, namely, by a spherical portion having its place of stable equilibrium in the middle of the magnetic field (2812.), by a fluid portion tending to expand equatorially and become an oblate spheroid (2813.), and by the equatorial pointing of an elongated portion (2812.). If pointed magnetic poles are used, then the effects are very much stronger, but are exactly the same in kind, and dependent upon the same causes and polar conditions.

2830. There are another set of effects produced, which are either the results of the axial polarity just referred to, or else may be considered as consequences of the condition of the equatorial parts of the conductors (2824.). Two balls of iron, in a field of equal force, if retained in a plane at right angles to the line of force, *i. e.* with their equatorial parts in juxtaposition, separate from each other with considerable power (2814.), and the probability is that two infinitely weaker bodies of the paramagnetic class would separate in like manner. Two portions of phosphorus, being a diamagnetic substance, have been found also to separate under the same circumstances (2815.).

2831. The motions here are of the same kind, whereas they might have been expected to be the reverse (2816.) of each other; still they are perfectly consistent. The diamagnetics ought to separate, for the field is stronger in lines of magnetic force between them than on the outsides, as may easily be seen by considering the two spheres D D in fig. 6; and therefore this motion is consistent, and is in accordance generally with the opening or set equatorially, either of separate portions or of a continuous mass of such substances (2829.), in their tendency to go from stronger to weaker places of action. On the other hand, the two balls of iron, P P, have weaker lines of force between them than on the outside; and as their tendency is to pass from weaker to stronger places of action, they also sepa-

Fig. 6.



rate to fulfil the requisite condition of equilibrium of forces. Finally, a paramagnetic and a diamagnetic body attract each other (2817.); and they ought to do so, for the diamagnetic body finds a place of weaker action towards the paramagnetic body, and the paramagnetic substance finds a place of stronger action in the vicinity of the diamagnetic body, D P, fig. 6.

2832. I have frequently spoken of iron in illustration of the action of paramagnetic conductors, and considered the polarity which it acquires as the same with that of these conductors; but I must now make clear a distinction, which exists in my mind, with regard to the polarity of a magnet, and the polarity, as I have called it, due to mere conduction. This distinction has an important influence in the case of iron. A permanent magnet has a polarity in itself, which is possessed also by its particles; and this polarity is essentially dependent upon the power which the magnet inherently possesses. It, as well as the power which produces it, is of such a nature, that we cannot conceive a mere space void of matter to possess either the one or the other, whatever form that space may be supposed to have, or however strong the lines of magnetic force passing across it. The polarity of a conductor is not necessarily of this kind, is not due to a determinate arrangement of the cause or source of the magnetic action, which in its turn overrules and determines the special direction of the lines of force (2807.), but is simply a consequence of the condensation or expansion of these lines of force, as the substance under consideration is more or less fitted to convey their influence onwards. It is evidently a very different thing to originate such lines of power and *determine their direction* on the one hand, and only to assist or retard their progression without any reference to their direction on the other. Speaking figuratively, the difference may be compared to that of a voltaic battery and the conducting wires, or substances, which connect its extremities. The stream of force passes through both, but it is the battery which originates it, and also determines its direction; the wire is only a better or worse conductor, however by variation of form or quality it may diffuse, condense, or vary the stream of power.

2833. If this distinction be admitted, we have to consider whether iron, when under the influence of lines of magnetic power, becomes a magnet and has its proper polarity, or is a mere paramagnetic conductor with conducting powers of the highest possible degree. In the first place, it would have the real polarity of the magnet, in the second only that which I assign to oxygen and other conducting bodies. To my mind the iron is a magnet. It can be raised as a *source* of lines of magnetic power to an extreme degree of energy in the electro-magnet; and though, when very soft, it usually loses nearly all this power upon the cessation of the electric current, yet such is not the case if the mass of metal forms a continuous circuit or ring, for then it can retain the force for hours and weeks together, and is evidently for the time an original source of power independent of any voltaic current. Hence I think that the iron under the influence of lines of magnetic power becomes a magnet; and though it then has the same kind of polarity, as to direction, as a mere paramagnetic conductor, subject to the same lines of force, still with a great difference; for as the internal particles of iron become in a degree each a system producing magnetism, so their polarity is correlated and combined together into a polar whole, which, being infinitely more intense, may also be very different in the disposition of its force in different parts, to that equivalent to polarity, which a mere conductor possesses.

2834. It appears to me also as very probable, that when iron, nickel and cobalt, are heated up to the respective temperatures at which they lose their wonderful degree of power (2347.) and retain only so small a portion of it as to require the most sensible test to make it manifest (2343.), they then have passed into the condition of paramagnetic conductors, have lost all ability to acquire that state of internal polarity they could assume as magnets, and now have no other polarity than that which belongs to them as masses of paramagnetic matter (2819.). It is also probable that in many states of combination these metals may take up the mere conducting state; for instance, that whilst in the protoxide, iron may constitute a magnet, in the peroxide it is only a conductor; and in this respect it is not a little curious to find oxygen, which as a gas is a paramagnetic body (2782.), reducing iron down to, and indeed far below its own condition, weight for weight. In their various salts also and solutions, these metals may, in conjunction with the combined matter, be acting only as conductors.

2835. Perhaps I ought not to have called the condition of concentration or expansion of the lines of magnetic force in the bodies acting as conductors, a polarity; inasmuch as true magnetic polarity depends essentially and entirely on the *direction* of the line of force, and not on any mere compression or divergence of these lines. I have done so only that I might point with the more facility to facts and views that have heretofore been associated with some supposed polarity in the bodies which, whether paramagnetic or diamagnetic, I have been considering as mere conductors, and I hope that no mistake of my meaning will arise in consequence. I have already asked for such liberty in the use of phrases (lines of force, conducting power, &c.) (2149. 2797.) as may, for the time, set me free from the bondage of preconceived notions; these are, for that very reason, exceedingly useful, provided they are for the time sufficiently restricted in their meaning, and do not admit of any hurtful looseness or inaccuracy in the representation of facts.

¶ iii. *Magnecrystallic conduction**.

2836. The beautiful researches of Plücker in relation to magneoptic phenomena cannot have been forgotten, and I hope that my own experiments on magnecrystallic results (2454, &c.) are remembered in conjunction with his; the phenomena described by us are, as I believe, due to a common cause, and are the same in kind; and as far as they are presented by pure transparent bodies, are I think brought by Plücker into a proper relation to the positive and negative optic axis of such bodies*. In these cases a crystalline body sets powerfully, or takes up a particular position when placed in a field of magnetic force (2464. 2479. 2550.), without reference to its paramagnetic or diamagnetic character (2562.), and also without assuming any state which it can on its removal bring away with it (2504.).

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* I must refer here to the important paper by MM. Tyndall and H. Knoblauch on this subject in the Philosophical Magazine, 1850, vol. xxxvii. p. 1. M. F.—January 6, 1851.

2837. If the idea of conduction be applied to these magnecrystallic bodies, it would seem to satisfy all that requires explanation in their special results. A magnecrystallic substance would then be one which in the crystallized state could conduct onwards, or permit the exertion of the magnetic force with more facility in one direction than another; and that direction would be the magnecrystallic axis. Hence, when in the magnetic field, the magnecrystallic axis would be urged into a position coincident with the magnetic axis, by a force correspondent to that difference, just as if two different bodies were taken, when the one with the greater conducting power displaces that which is weaker.

2838. The effect of position would thus be accounted for (2586.); and also the greater aptness for magnetic conduction in one direction than in another (2588. 2591.): and, what appeared to me as an anomaly in the supposition, that a line of force could have reference indifferently to any part of a plane (2600.) disappears. That heat should take away this conducting power (2570.) seemed perfectly consistent with what we know of the effect of heat on the magnetic condition of iron, oxygen, &c., and also upon the conducting power for electricity in such cases as platina, sulphuret of silver, &c. Finally, the assumption did not appear inconsistent with the state which the body seems to assume for the time during which it is under the magnetic force (2609. &c.).

2839. But if such a view were correct, it would appear to follow that a diamagnetic body like bismuth ought to be less diamagnetic when its magnecrystallic axis is parallel (as nearly as may be) to the magnetic axis, than when it is perpendicular to it. In the two positions it should be equivalent to two substances having different conducting powers for magnetism, and therefore, if submitted to the differential balance, ought to present differential phenomena, corresponding in kind to those of oxygen and nitrogen (2774.), or phosphorus and bismuth, or any other two differing bodies. Though I have given certain results on a former occasion which seemed to bear on this point (2551. 2552. 2553.), they are not satisfactory in the present state of our knowledge, because the difference, if any, would be small (2552.), and quickly hidden by the employment of a single pointed pole. Other experiments, formerly described (2554–2561.), would not show a small difference in diamagnetic force (though quite fitted for their intended purpose), because they were made with flat-faced poles, and a field nearly equal in magnetic power.

2840. The differential torsion balance (2773.) enabled me to return to this matter with better hopes of success. A consistent group of bismuth crystals was selected

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* Philosophical Magazine, 1849, vol. xxxiv. p. 450.

(2457.) and hung up on one side of the double cone core (2738.), whilst a cylinder of flint-glass was opposed to it on the other. The flint-glass was to be a standard of reference, and therefore neither its place on the balance nor condition was altered during the experiment. The bismuth group was placed with its magnecrystallic axis horizontal, and so that it could be turned in a horizontal plane, that the axis might be at one time parallel to the magnetic axis (or lines of force), and at other times perpendicular to it, but without any alteration of the distance of its centre of gravity from the opposed glass cylinder. Hence, having either one position or the other, it could still be compared with the cylinder.

2841. The magnecrystallic axis was first made parallel to the core or magnetic axis, the magnetic power developed, and when the diamagnetic bodies had taken their position of rest or stable equilibrium, the place of the balance lever was observed and recorded by means of a ray of light reflected from a mirror attached to it. Then the bismuth was turned through 90°, or until its magnecrystallic axis was perpendicular to the axis of the double cone core; and now, when the magnet was excited, the place of the bismuth was found to be further out from the core than before. On being turned through 90° more, so as to be in a position diametral to the first (2461.), its place was again a little nearer to the magnet; and when in the fourth position, which is diametral to the second, then it was further out. Thus the crystallized bismuth proved to be diamagnetic in different degrees, according with certain directions of its magnecrystallic axis, being more diamagnetic when this axis was perpendicular or transverse to the lines of magnetic force, than when it was parallel to them; and thus the expectation founded upon theoretical considerations (2839.) was confirmed.

2842. I tried to obtain similar results with a cube of calcareous spar (2597.); for it is evident that if its optic axis, being in a horizontal plane, is first placed parallel to the magnetic axis and then perpendicular to it, the body ought to be more diamagnetic in the first position than in the second, inasmuch as the latter is the position which it takes up under the influence of its magnecrystallic or magneoptic condition. I could not however obtain any distinct results, partly because its power is in all respects very inferior to the bismuth, partly because of the present imperfection of my torsion balance, and partly because of the size and shape of the calcareous spar. A sphere or a cylinder, having the optic axis perpendicular to the axis of the cylinder, would be more correct as forms of the substances to be tried.

2843. In concluding this part of the subject relating to the magnetic conducting power, I will now refer to some of the cases which I think experimentally establish its *existence* in the two subdivisions of magnetic bodies (2805.). The place and position of iron in a field of equal force (2810. 2811.) is no doubt a result of the extraordinary power which this body has of transmitting the magnetic force across the space which it occupies, whether the particles of the iron be considered as polar or not

(2832.), and therefore I accept the converse phenomena as to place and position of a diamagnetic body (2812. 2813.) as proof that it has less power of transmitting the magnetic force than the space it occupies, and from that conclude that it conducts diamagnetically (2802.).

2844. The separation of paramagnetic bodies in the equatorial direction is a proof of the manner in which, by their better conduction, they disturb the position of the lines of force in the medium around them (2831.). The separation of two diamagnetic bodies, under the same circumstances, is an equal proof of the manner in which, by difference of conducting power, they also disturb the disposition of the force (2831.). The equatorial attraction of a paramagnetic and a diamagnetic body for each other, when they are in a medium, which in conducting power is between the two (2831.), is a proof not only of conduction in both, but also of their reverse condition in respect of each other and the medium.

2845. The place of a crystal of bismuth, either nearer to or further from the magnetic axis (2841.), according as its magnecrystallic axis is parallel or perpendicular to the axial line, is also a case of the difference of conducting power, and therefore of the possession of that power by the diamagnetic body. Many other cases might be quoted in illustration of the existence of that power which I assumed as conducting power (2797.), and which probably nobody may be inclined to deny. I will suppose that the above are enough to explain my meaning.

2846. It is hardly necessary for me to say that magnetic conduction does not mean electro-conduction, or anything like it. The very best electro-conductors, as silver, gold and copper, are below mere space in their ability to favour the transmission of magnetic force, so deficient are they in what I have called magnetic conduction. There is a striking analogy between this conduction of magnetic force and what I formerly called specific inductive capacity (1252. &c.) in relation to static electricity, which I hope will lead to further development of the manner in which lines of power are affected in bodies, and in part transmitted by them.

¶ iv. *Atmospheric magnetism** †.

2847. It is to me an impossible thing to perceive, that two-ninths of the atmosphere, by weight, is a highly magnetic body, subject to great changes in its magnetic character, by variations in its physical conditions of temperature and condensation or rarefaction (2780.), and at the same time subject to these physical changes in a high degree, by annual and diurnal variations, in its relation to the sun, without being persuaded that it must have much to do with the disposition of the magnetic forces upon the surface of the earth (2796.), and may perhaps account for a large part of the annual, diurnal and irregular variations, for short periods, which are found to occur in relation to that power. I cannot pretend to discuss this great question with much understanding, seeing that I have very little of that special knowledge which has been accumulated by the exertions of the great and distinguished labourers, Humboldt, Hansteen, Arago, Gauss, Sabine, and many others, who have wrought so zealously at terrestrial magnetism over the surface of the whole earth. But as it has fallen to my lot to introduce certain fundamental physical facts, and as I have naturally thought much upon the general principles which tend to establish their relation to the magnetic actions of the atmosphere, I may be allowed to state these principles as well as I can, that others may be placed in possession of the subject. If the principles are right, they will soon find their special application to magnetic phenomena as they occur at various parts of the globe.

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* A most important paper by Professor CHRISTIE "On the Theory of the Diurnal Variation of the Magnetic Needle," appears in the Philosophical Transactions for 1827, p. 308. Led by the discoveries of SEEBECK in thermo-magnetism and the experiments of CUMMING, he was induced to search how far the idea of thermo-currents or thermo-magnetic polarity would apply to the natural phenomena, and concludes (p. 327), that, admitting that the *earth and the atmosphere* are substances in which such action can under any circumstances take place, these experiments would indicate that *any portion of the earth bounded by parallel planes with the atmosphere surrounding it, would become similarly polarized if one part were more heated than another.* Thus considering alone *the equatorial regions of the earth,* we should have *two magnetic poles on the northern side, and on the southern side two poles similarly posited; the poles of different names being opposed to each other on the contrary sides of the equator.*

† I ought to refer the readers of my paper to a theory of the *cause* of the daily variations by M. A. DE LA

2848. The earth presents us with a spheroidal body, which, consisting of both paramagnetic and diamagnetic substances, disposed with much irregularity as regards its large divisions of earth and ocean, are also equally irregularly disposed and intermingled in its smaller portions. Nevertheless it is, on the whole, a magnet, and, as far as we at this moment are concerned, an original source of that power. And

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Rive, founded upon the idea of thermo-electric currents in the atmosphere and earth; it will be found in a memoir entitled 'On the Diurnal Variation of the Magnetic Needle.' Annales de Chimie, 1849, xxv. p. 310.

A friend has recently called my attention to an observation by M. E. Becquerel, which has reference to the present subject, and is in the following words. "If we reflect that the earth is encompassed by a mass of air, equivalent in weight to a layer of mercury of 30 inches, we may inquire whether such a mass of magnetic gas, continually agitated and submitted to the regular and irregular variations of pressure and temperature, does not intervene in some of the phenomena dependent on terrestrial magnetism. If we calculate in fact what is the magnetic force of this fluid mass, we find that it is equivalent to an immense plate of iron, of a thickness a little more than $\frac{1}{10}$th of a millimetre of diameter (?), and which covers the whole surface of the globe." This passage is at pp. 341, 342 of vol. xxviii. Annales de Chimie, 1850, being contained in an excellent memoir, in which the author has well worked out those differential actions of different media, which I developed generally *five* years ago. Experimental Researches, 2357. 2361. 2406. 2414. 2423. &c. By such means he has rediscovered the magnetic character of oxygen and taken measurements of its force, being evidently unacquainted with the account that I gave of this substance in relation to nitrogen and other gases *three* years ago, in a letter published in the Philosophical Magazine for 1847, vol. xxxi. p. 401, and also in Poggendorff's Annalen and elsewhere;—hence the observations above. I cannot wonder at this, for I myself was not aware of M. E. Becquerel's paper until very lately. In my letter of 1847, I speak of oxygen as being magnetic in common air, p. 410; in carbonic acid, p. 414; in coal-gas, p. 415; in hydrogen, p. 415, its power then being equal to its gravity. I say that air owes its place to the oxygen and nitrogen in it, p. 416, and tried to separate these constituents by attracting the oxygen and repelling the nitrogen. At the end of the paper I hesitate in deciding where the true zero between magnetic and diamagnetic bodies is to be placed, and refer to the atmosphere as being liable to affections under the magnetic influence of the earth. It was these old results which led me on to the present researches. M. F.—Nov. 28, 1850.

though we cannot conceive at present that all the particles of the earth contribute, as sources, to its magnetism, inasmuch as many of them are diamagnetic, and many non-conductors of electric currents, yet it is difficult to say that any large portion is not concerned in the production of the force; hereafter it may be necessary, perhaps, to consider certain parts as mere conductors, *i. e.* as parts merely permeated by the lines of force, originating elsewhere, but for the present the whole may be assumed, according to the theory of GAUSS, as a mighty compound magnet.

2849. The magnetic force of this great system is disposed with a certain degree of regularity. We have the opportunity of recognising it only as it is exhibited in one surface, which, being very irregular in form, is always the same to us, for we rarely, if ever, pass out of it; or if we do, as in a balloon, only to an insensible extent. This is the surface of the earth and water of our planet. The magnetic lines of force which pass in or across *this surface* are made known to us, as respects their direction and intensity, by their action on small standard magnets; but their average course or their temporary variations *below or above*, i. e. in the air above, or the earth beneath, are only dimly indicated by variations of the force at the surface of the earth, and these variations are so limited in their information, that they do not tell us whether the cause is above or below.

2850. The lines of force issue from the earth in the northern and southern parts with different but corresponding degrees of inclination, and incline to and coalesce with each other over the equatorial parts. Their general disposition is represented by the system, which emanates from a globe having within one or two short magnets adjusted in relation to the axis. There seems reason to believe, from the analogy of such globes to the earth, that the lines of magnetic force which proceed from the earth return to it; but in their circuitous course they may extend through space to a distance of many diameters of the earth, to tens of thousands of miles. Messrs. GAY-LUSSAC and BIOT, in their ascent in a balloon, perceived some indication of a diminution in the intensity of the magnetic force at a height of about four miles from the surface; but we shall shortly perceive that they might be at the time in the midst of influences sufficient to account for all the effect, so that none of it might be occasioned by removal from the earth as a magnet. The increase of the intensity of the magnetic force, as we proceed from the equator towards the poles, accords with the idea of the enormous extension of this power.

2851. These lines proceed through space with a certain degree of facility, of which a general idea may be gained from ordinary knowledge, or from experiments and observations formerly made (2787.). Whether there are any circumstances which can affect their passage through mere space, and so cause variations in their condition; whether variations in what has been called the temperature of space could, if they occurred, alter its power of transmitting the magnetic influence, are questions which cannot be answered at present, although the latter does not seem to be entirely beyond the reach of experiment.

2852. This space forms the great abyss into which such lines of force as we are able to take cognizance of by our observing instruments, which issue from the earth, proceed, at least at all parts of the globe where there is a sensible dip; but, as it were, between the earth and this space, there is interposed the atmosphere, which, however considerable we may estimate it in height, is so small when compared to the size of the earth, or to the extent of space beyond it into which the lines of force pass, that the idea of its being a changeable, active something interposed *between* two systems far more extensive and steady in their nature and condition, will not lead to any serious error. It is at the bottom of this atmosphere that we live and make all our inquiries, whether by observation or experiment.

2853. The atmosphere consists, as far as we are concerned at present, of four volumes of nitrogen and one volume of oxygen, or by weight, of three and a half parts of the former and one part of the latter. These substances are nearly uniformly mixed throughout, so that, as regards their manner of investing the earth, they act magnetically as a single medium; nor does there seem to be any tendency in the terrestrial magnetic forces to cause their separation*, though they differ very strikingly in their constitution as regards this power.

2854. *The nitrogen* of the air does not appear to be either paramagnetic or diamagnetic; if removed from zero, in either of these respects, it is only to a very small extent (2783. 2784.). Whether dense or rare, it has apparently the same relation to and equality with space, as far as the present means of observation have proceeded. As respects the other element of change, namely, temperature, I concluded, from former imperfect experiments†, that nitrogen became more diamagnetic when heated than before; but as it was then mixed with the oxygen of the air, and the results were mingled together, I have, for the purposes of the present research, repeated the experiments far more carefully.

2855. A small helix of platinum wire, fixed at the end of thicker copper wires, could be placed in any position beneath the poles of the great electro-magnet, and being ignited by a voltaic battery, served to raise the temperature of the gas around it. The magnetic poles were raised, were terminated by hemispheres of soft iron 0·76 of an inch in diameter and 0·2 of an inch apart, and were covered by a glass shade, resting upon a thick flat bed of vulcanized caoutchouc. A tube passed through the bed, rising up to the top of the shade, by which any required gas could be introduced. A very thin plate of mica, about 3 inches square, was covered with an attenuated coat of wax on the upper side, and fixed horizontally over the magnetic poles within the shade. The small platinum helix was so placed as to be beneath the space, between the poles, and a little on one side of the axial line, so that a current of hot air rising upwards from it, could pass to the mica plate, and by melting the wax show where it came against the mica.

2856. All acted exceedingly well, *air* being in the glass shade. When there was no magnetic power on, the hot air from the ignited helix rose perpendicularly, and melted a neat round portion of the wax, showing the place of the current under natural circumstances; but when the magnet was thrown into action, then the wax on the mica remained unchanged, the hot air being thrown so far away from the axial line, and so cooled by its forcible mixture with the neighbouring air, as to be unable to melt a spot of wax anywhere. The moment the magnetic power was suspended, the column of hot air rose vertically and regained its original position.

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* Philosophical Magazine, 1847, vol. xxxi. p. 416.

† Ibid. p. 418.

2857. *Carbonic acid gas* was then sent into the shade, until twice as much as the contents of the shade had passed through the pipe (2855.); but as it was heavy and the common air could make its way out only at the bottom of the shade, there was no doubt air mixed with the carbonic acid, which at last remained about the poles. The platinum coil being now heated, the column of hot gas rose vertically, as before. On putting on the magnetic force it was deflected from the axial line, passing equatorially, and melted the wax about half an inch off from the former place. Believing that even this effect might be due to the air mingled with the gas, other two volumes of carbonic acid gas were directed into and through the vessel. After this the magnetic force caused much less deflection of the rising column. Two volumes more of carbonic acid were sent through, and now the hot current of gas rose so nearly vertical that there was scarcely any sensible difference of its place when the magnetic power was in full action, or when it was entirely absent. Hence I conclude that carbonic acid gas is very little affected in its diamagnetic relations by a difference of temperature equal to that between natural temperatures and a full red heat.

2858. *Nitrogen.*—This gas was prepared by passing common air slowly over burning phosphorus, and after being washed for twelve or fourteen hours, was sent into the shade so as to displace the carbonic acid. As it was lighter than the latter, it performed that service very well, and the portion remaining in the vessel probably contained no other oxygen or air than that it carried in with it. This nitrogen being then heated by the platina coil, was almost as indifferent to the magnet as the carbonic acid. The heated column rose (nearly) to the same spot against the mica, whether the magnetic power was active or not. It went outwards or equatorially a very small degree when the magnet was active, but this I attributed to a little oxygen still left with the nitrogen; and indeed nitric oxide gas shows oxygen in nitrogen so prepared. The platina coil was raised to as high a temperature as it could well support without fusion, and yet there was only this small effect sensible; hence I conclude that hot nitrogen is not more diamagnetic than cold nitrogen, and that indeed its magnetic relation is noways affected by such change of temperature.

2859. I raised the French shade (2855.) an inch for a moment, and then instantly placed it down again; and now, on making the magnet active and the coil hot, there was so much effect of dispersion of the gas within, that the melted spot of wax appeared nearly an inch outside of the standard place, yet only a very small portion of air or of oxygen could have entered the vessel under these circumstances.

2860. The nitrogen of the air is therefore, as regards the magnetic force, a very indifferent body; it does not appear to be either paramagnetic or diamagnetic; neither does it present any difference in its relation, whether it be dense or rare, or at high or low temperatures. I formerly found that the diamagnetic metals, when heated, did not seem to change in their relation to the magnet (2397.), and this now appears to be the case with such neutral or diamagnetic bodies as nitrogen and carbonic acid gases.

2861. *The oxygen* of the air differs in a most extraordinary degree from the nitrogen. It is highly paramagnetic, being, bulk for bulk, equivalent to a solution of protosulphate of iron, containing, of the crystallized salt, seventeen times the weight of the oxygen (2794.). It becomes less paramagnetic, volume for volume (2780.), as it is rarefied, and apparently in the simple proportion of its rarefaction, the temperature remaining the same. When its temperature is *raised*, the expansion consequent thereon being permitted[*], it loses very greatly of its paramagnetic force; and there is sufficient reason, from a former result with air[†], to conclude, that when its temperature is lowered its paramagnetic condition is exalted. How much its paramagnetic intensity might be increased by lowering it to the temperature of freezing mercury, as at the north or south poles of the earth, we cannot at present tell. Though a gas, it is apparently like the solid metals, iron, nickel or cobalt, when they are within the range of temperature which affects their magnetic forces; and it may, perhaps, like them, rise by cooling to a very high state.

2862. These relations it preserves when mingled with nitrogen in the air, as long as its physical and chemical conditions remain unchanged; but it is not irrelevant to remark, that every operation by which this active part of the atmosphere changes in its nature and passes into combinations, takes away its paramagnetic powers, whether the result be solid, liquid or gaseous.

2863. Hence the atmosphere is, in common phrase, a highly magnetic medium. The air that stands upon every square foot of surface on the earth, is equivalent, in magnetic force, to 8160 lbs. of crystallized protosulphate of iron (2794. 2861.). This medium is, by every change in its density, whether of the kind indicated by the barometer, or caused by the presence or absence of the sun, changed in its magnetic relations. Further, every variation of temperature produces apparently its own change of force, in addition to that caused by the mere expansion or contraction in volume, and none of these alterations can happen without affecting the magnetic force emanating from the earth, and causing variations, both in its intensity and direction, at the earth's surface. Whether these changes are in the right direction and sufficient in quantity to supply a cause for the variations of the terrestrial magnetic power, is the point now to be considered, for the illustration of which I will endeavour to construct a type case, and then apply it, as well as I can, to the natural facts.

2864. Let us assume the existence of two globes of air distinct from the surrounding atmosphere, by a difference of temperature or by a difference of density: the assumption is not too extravagant for an illustration, since Prout showed that there were masses of air, larger or smaller, floating about in the atmosphere, and singularly distinct from the surrounding parts, by temperature and other circumstances. Not to complicate the expression, we will leave out of view, at present, the attenuation upwards, and will consider one of these globes as *colder* or denser than the contiguous parts, and that it is in a portion of space which without it would present a field of equal magnetic force, *i. e.* having parallel lines of equal intensity of force passing across it.

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[*] Philosophical Magazine, 1847, vol. xxxi. p. 417.

[†] Ibid. p. 406.

2865. The air of such a globe will *facilitate* the transmission of the magnetic force through the space which it occupies (2807.), making it superior, in that respect, to the surrounding atmosphere or space, and therefore more lines of magnetic force will pass through it than elsewhere (2809.). The disposition of these lines, in respect of the line of the dip of the place, will be something like what is represented in fig. 7, (2874.), and consequently the globe will be polarized as a conductor (2821. 2822.) of the paramagnetic class. Hence the intensity of the magnetic force and its direction will vary, not only within but without the globe, and these will vary in opposite directions, in different places, under the influence of laws which are perfectly regular and well known.

2866. First, as regards the *intensity*, which before was uniform (2864.). If the intensity is to be considered as expressing the amount of force which passes through any given place, then, in consequence of the definite amount of power which belongs to any section, as *a a*, of a given amount of lines of magnetic force (2809.), a concentration of these lines towards the middle, P, will cause an increase of intensity at that part, and a diminution at some other parts, as *b b*, from whence the influence of the power has been partly removed. Hence, supposing the normal condition to exist at *a*, if a test of intensity were carried from *a* to P, it would gradually enter parts *b* and *c*, in which the intensity was less than the normal condition, and these might be either without or within the globe P, or both (according to its temperature relative to the surrounding air, its size and other circumstances); it would then arrive at parts having the normal intensity; and lastly, at parts, P, having an intensity greater than the surrounding space; as it went outwards, on the opposite side of P, corresponding variations would occur in the reverse order.

2867. On transporting the test upwards, in the direction of the dip from *e*, where the intensity may be considered as normal, it would gradually occupy positions at *f g*, &c., in which the intensity would increase until it arrived at P, after which it would pass through places of less and less intensity, until at *p* it would again find the force in the normal state. If the test, in being carried upwards, be not taken along *the line of the dip*, then it will of course pass through variations like those described on the line *a* P, growing more and more in extent until the direction coincides with the line *a* P, which is at right angles to the dip and where they are at a maximum. Hence, to pass upwards through such a globe of cold air in our latitude, where the dip is 70° nearly, and at the equator, where it is 0°, would be a very different matter, and the necessary natural results of such a difference ought to appear hereafter.

2868. But a magnetic needle or bar is not a test of such intensity, *i. e.* it will not tell these differences, or it may tell them in a contrary direction. To understand this point, we have to consider that a needle vibrates by gathering upon itself, because of its magnetic condition and polarity, a certain amount of the lines of force, which would otherwise traverse the space about it; and assuming that it underwent no change by change of temperature, it would be affected in proportion to any variations in the intensity of these lines, provided everything else remained the same. But being under natural circumstances surrounded by the atmosphere, which is a medium liable to variation in its magnetic condition, both by heat and rarefaction, and by these variations affects the intensity or quantity of the force, it will vary in its indications by variations in these conditions. Thus, for instance, if it were in a large sphere of oxygen, I expect that it would, by its number of vibrations or otherwise, indicate a certain intensity; if the oxygen were expanded, that it would indicate a higher intensity, although the same amount of lines of force and magnetic energy were passing through the oxygen as before. If the oxygen were made dense, then becoming a better conductor, I presume it would convey onwards *more* of the force and the magnet *less*, for the power would be partly transferred from the unchanging magnet to the improving conductor around it.

2869. These experiments can hardly be made with oxygen except by means of extremely delicate apparatus, but like effects are easily shown experimentally in selected analogous cases. Thus let a thin small tube of flint-glass, about 1 inch long and ½ an inch in diameter, be filled with a saturated solution of protosulphate of iron, and suspended horizontally by cocoon-silk (2279.) between the poles of the electro-magnet, in a vessel which may either contain air or water, or other media (2406.). In air it will point axially, and will be analogous to a needle under the earth's influence, and it will point with a certain amount of force. Fill the vessel with water, and now it will point with more force than before, though the water is a worse magnetic conductor than the air which was previously there; and it is precisely because the water *is* a worse conductor that the liquid magnet or test indicates more power. Increase the conducting power of the surrounding medium by adding sulphate of iron to it, and the indication of strength by the tube goes on diminishing, first returning to the degree of power it had in air, and then descending to lower gradations, for it returns with less and less force to its axial position when disturbed from it. So the magnetic needle employed for measuring intensity or magnetic force (for the same meaning is at present understood by the two terms), indicates, in a certain manner, the power thrown upon itself, and, I conclude, accurately, provided the condition of the surrounding medium remains magnetically unchanged; but if it be placed in different media or in an altering medium, I expect that it will not measure accurately the intensity in them, *i. e.* it will not measure directly the amount of force passing relatively through them. The difference in air under different conditions would be very small, still it is that difference which concerns us in *atmospheric magnetism*; and it is very important to know, whether, when the magnet indicates an increased intensity of force, it is altogether due to a real increase of the amount of the power at its source as it comes to us from the earth, or in part to a change in the magnetic constitution of the space around the magnet hitherto unknown to us.

2870. If what is now often indifferently called magnetic force or intensity have its results distinguished as of two kinds, namely, those of *quantity* and those of *tension*, then we shall more readily comprehend this matter. At present a needle shows both these as magnetic force, making no distinction between them, yet they produce effects on it often in opposite directions; for as they increase or diminish they both affect the needle alike; but as it is assumed that the tension can change whilst the quantity remains the same, and the quantity can be altered, yet the tension remain unaffected, the result by the needle will then be uncertain. If the tension in a given region be increased by diminishing the conducting power, the needle will show *increased force*; if it be increased by an increase of magnetic power in the earth from some internal action, the needle will still show *increased force*, and will not distinguish the one effect from the other. If the quantity in a region be increased by increasing the conducting power, the needle will show no such increase; on the contrary, it will indicate *diminution* of force, because the tension is diminished; or if the quantity be diminished by diminishing the conducting power, it will show *increased* force. The force might even lose in quantity and gain in tension in such proportions that the needle should show no change; or it might gain in quantity and lose in tension, and the needle still be entirely indifferent to the whole result.

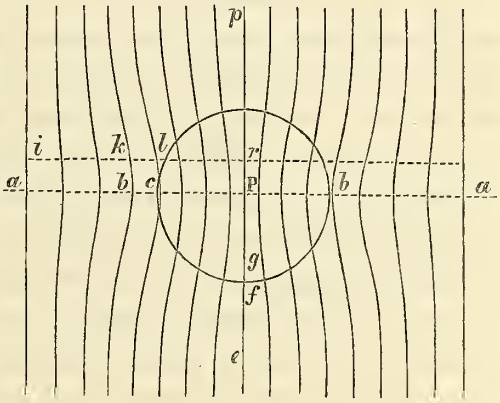
2871. If my view be correct, then the magnet is not, as at present applied, a perfect measure of the earth's magnetic force; for that may not change when the magnet by the influence of the different conditions of day and night, or of summer and winter, may show a difference. How *far* these uncertainties in its indication may affect the value of the observations made on the horizontal and vertical components of the earth's magnetic force as indications of that which they are expected to tell us, I do not know; but involving, as the effects do, two very different conditions, namely, variation of the conducting power and variation of the amount of force at its source, the one of which is chiefly in the atmosphere and the other in the earth, it seems to me to be of great consequence to the development of the theory of terrestrial magnetism, to have some method, if possible, of distinguishing these two points or effects from each other.

2872. Referring again to the model globe, fig. 7 (2874.), it appears to me, that if a magnet be used as the intensity test, it will indicate a less intensity at P rather than a greater one, for the very reason that the conducting power of the whole globe has been increased; and also, though the apparent diminution of intensity will probably be greater there than elsewhere, that the effect will occur in other parts, especially those on the right and left, and even at *b* and *b*, where the power transmitted, instead of being more, as at P, is really less than the portion transmitted in the normal or equable state of the magnetic field. With a diamagnetic globe of air, *i. e.* one warmer or more rarefied than the surrounding space (2877.), though it would convey less power as being a worse conductor, still it should cause the magnet to set with greater force, and so give an indication of increased intensity, and that also both within and equatorially without the globe.

2873. If it be true that the changes of the medium (2869.) can thus affect the magnet, and that such changes can rise up to a sensible degree in the gases, then a magnet might make a different number of vibrations in a given time in oxygen and nitrogen gases of the same density, for they are very different in their magnetic relations. It should make the greatest number in nitrogen; perhaps a delicate torsion balance would be a still more sensible test of such a result; but it is probable that the space around the needle should be large, and it would be requisite to ascertain that the two media opposed equal mechanical resistance to the vibrating needle.

2874. The variation of the *direction* caused by the typical globe (2864.) might be oblique to the horizontal and vertical planes, and consequently give results of declination and inclination, either separately or together. The direction would not vary in a central line parallel to the general dip of the surrounding space (fig. 7). Along another central line perpendicular to this (*i. e.* any line in the equatorial plane), *a* P, there would also be no variation of the direction, but in any other position there would be variations. Thus in the line *i r*, as the free needle passed from *i* to *k*, its lower end would be carried inwards towards the central line of dip P; this effect, after attaining a maximum, perhaps at *l*, would gradually diminish again, and by the time the needle had reached *r* the dip would be normal. Corresponding effects would occur on the opposite side of the axial line *p e*; and if a needle be considered as in any place the dip of which is thus affected, and then be conceived as travelling in a circle round the axial line *p e*, it would always be in the surface of a cone, the apex of which is below.

Fig. 7.



2875. On the other hand, if the variations of the dip below the equatorial plane *a* P be considered, they will be equal in amount, but in the reverse direction, so that the magnetic needle, when deflected from its normal position, would have its upper end inclined inwards towards the axial line *p e*; or if moved round the axial line would always be in a conical surface, the apex of which is above.

2876. So the dip would vary in such a globe of air in every azimuth; and it would also vary in opposite directions in the upper and lower parts of the globe, and of the affected surrounding space.

2877. If we assume the existence of another typical globe of air (2864.), having a higher temperature than the surrounding atmosphere, then its condition will be that of a diamagnetic conductor, and will be represented by fig. 9 (2807.); and it will have power to affect both the intensity and the direction of the lines of force, in conformity with the action of the former globe, but in the contrary order. As regards the action of these globes, consequent upon the direction of the lines of force in and about them upon a needle coming within their influence, it may, in part, be represented by a magnet placed either in the direction of the needle for the cold globe, or in the reverse direction for the warm one; but as the lines of force of the combined system of the earth and such a magnet are very different in their arrangement to the lines of the earth affected by masses of warm or cold air having only conduction polarity (2820.), it would be too much to say that they correspond, or that the effects on the intensity or direction would be the same for similar distance from the centre of the globe of air and the representative magnet.

Fig. 8.

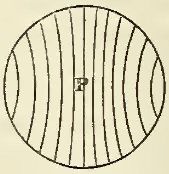
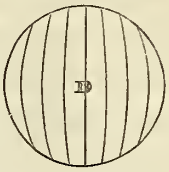


Fig. 9.



2878. In endeavouring to proceed, from these hypothetical and comparatively simple cases, which are given only to lead the mind on from the results of experiment to the supposed condition of matters as regards our atmosphere and the earth, we have to consider, that though there will be an effect, and though the intensity and direction of the magnetic force, upon the surface of the earth, must vary with changes of temperature and density of the atmosphere, still it will be in a manner very different from that represented by the typical globe of air, for the latter is a case which will never occur, though the variations of the natural case are almost infinite. Still the comparison holds in principle, and we may expect that as the sun leaves us on the west, some effect, correspondent to that of the approach of a body of cold air from the east, will be produced, which will increase and then diminish, and be followed by another series of effects as the sun rises again and brings warm air with him.

2879. The atmosphere diminishes in density upwards, and that diminution will affect the transmission of the magnetic force, but as far as it is constant, the effect produced by it will be constant too. The portion of the atmosphere which lies under the heating influence of the sun, as compared to its depth, will more resemble a slice of air wrapped round the earth than a globe. Still the inflection of the lines of force, both above and below this stratum, will occur, extending into space above and into the earth beneath (2848.), according to the known influence of magnetic power and its perfectly definite character (2809.). We are placed at the bottom of this layer of air, but as the atmosphere is denser there than higher up, and is also in many cases more affected there by changes of temperature, we are probably in a position where the inflections and variations due to the assumed causes exist in a considerable degree.

2880. There are innumerable circumstances that will break up, more or less, any general or average arrangement of the air temperature. For instance, the diversity of sea and land causes variations of temperature differently in different times of the year, and the extent to which this goes may be learned from the beautiful isothermal charts of Dove, now fortunately to be had in this country*. These variations may be expected to give, not merely differences in the regularity, direction and degree of magnetic variation; but because of vicinity differences so large as to be manifold greater than the mean difference for a given short period, and they may also cause irregularities in the times of their occurrence.

2881. On considering the probable results of the magnetic action of the atmosphere, it appears to me that if the terrestrial magnetic force could be freed from all periodical and small perturbations, and its disposition ascertained for any given time, it might still include certain effects constituting a part of atmospheric magnetism. For instance, there is more air, by weight, over a given portion of the surface of the earth at latitudes from 24° to 34°, than there is either at higher latitudes or at the equator; and that should cause a difference from the disposition of the lines of force which would exist if there were equality in that respect, or if the atmosphere were away. Again, the temperature of the air is greater at the equatorial parts than in latitudes north or south of it; and as elevation of temperature diminishes the conducting power for magnetism, so the proportion of force passing through these parts ought to be less, and that passing through the colder parts greater, than if the temperature of the air were at the same mean degree over the whole surface of the globe, or than if the air were away. Again, there is a greater difference in range of temperature of the air at the equator as we rise upwards than in other parts, and hence the lower part is not so good a conductor proportionately to the upper part, or to space, as elsewhere, where the difference is not so great; the magnetic power, therefore, should be in some degree weakened there, the lines of force being diverted, more or less, from the warm air and thrown into other parts, as the cooler atmosphere and space above, or the earth beneath, according to the principles before explained (2808. 2821. 2877.).

2882. The result of *annual variation* that may be expected from the magnetic constitution and condition of the atmosphere seems to me to be of the following kind. Assuming that the axis of rotation of the earth was perpendicular to the plane of its orbit round the sun, and dismissing for the present other causes of magnetic variation than those due to the atmosphere, the two hemispheres of the earth, and the portions of air covering them, would be affected and warmed alike by the sun, or at least would come into a constant relative state, dependent upon the arrangement of land and water; and the lines of magnetic force having taken up their position under the influence of the great dominant causes, whatever they may be, would not be altered by any annual change due to the atmosphere, since the daily mean of the atmospheric effect in a given place would at all parts of the year be alike. Under such circumstances the intensity and direction of the magnetic forces might be considered constant, presuming no sensible change to take place by the difference in distance from the sun which would occur in different parts of the orbit; and, as regards the two magnetic hemispheres, each would be the equivalent of and equal to the other, and they may for the time be considered in their mean or normal state.

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* Report of the British Association, 1848, Reports, p. 85.

2883. But as the axis of the earth's rotation is inclined 23° 28′ to the plane of the ecliptic, the two hemispheres will become alternately warmer and colder than each other, and then a variation in the magnetic condition may arise. The air of the cooled hemisphere will conduct magnetic influence more freely than if in the mean state, and the lines of force passing through it will increase in amount, whilst in the other hemisphere the warmed air will conduct with less readiness than before, and the intensity will diminish. In addition to this effect of temperature, there ought to be another due to the increase of the ponderable portion of the air in the cooled hemisphere, consequent upon its contraction and the coincident expansion of the air in the warmer half, both of which circumstances tend to increase the variation in power of the two hemispheres from the normal state. Then as the earth rolls on in its annual journey, that which at one time was the cooler becomes the warmer hemisphere, and consequently in its turn sinks as far below the average magnetic intensity as it before had stood above it, whilst the other hemisphere changes its magnetic condition from less to more intense.

2884. As the sum of the magnetic forces which crop out from the earth wherever there is dip on one side of the magnetic equator must correspond to the sum of like force on the other side (2809.), so they would not become more intense in one hemisphere, or more feeble in the other, without a corresponding contraction on the one hand, and enlargement on the other. The line of no dip round the globe may therefore be expected to move alternately north and south every year, or some effect equivalent to that take place. The condition of the two hemispheres under this view may be conceived by supposing an annual undulation of the force to and fro between them, during which, though neither the character nor the general disposition of the power be altered, there is in our winter a concentration and increase of intensity in the northern parts coincident with a diffused and diminished intensity in the south, and in summer the reverse.

2885. In respect of *direction*, alterations may also be anticipated. In the first place, and assuming that the magnetic poles and the poles of the earth coincide, the dip would increase in the cooling hemisphere towards the middle and polar parts; but it ought to diminish towards the magnetic equator, to accord with the concentration of the hemisphere of stronger power and enlargement of the weaker one; whilst on the other hand the dip ought to diminish at the polar and middle parts of the warming hemisphere and increase towards the magnetic equator. The magnetic equator would shift a little north and south of its mean place during each year, simultaneously with the whole system of magnetic lines. But as the magnetic poles do not coincide with those of the earth, or with what may be called the poles of the changing temperatures, so a cause of difference in direction will here arise.

2886. Again, it may be that as oxygen is cooled, its paramagnetic power may increase in a more rapid proportion than that of the change of temperature, so that the chief alteration of the disposition of the earth's force may be in the extreme northern and southern parts; and in combination with the holding power of the earth (2907.) may even cause a change the reverse of that expected above in lower latitudes. If in our winter the lines of force were to close together in the polar parts and to open out in lower latitudes, the balance of magnetic force would just as well be sustained as if *all* the lines in our hemisphere were to be compressed and strengthened, and be compensated for by a corresponding change in the south. In the former case, each hemisphere would balance its own forces, in the latter they would be balanced against each other. There can, I think, be no doubt, that as far as the mass of the earth and the space above our atmosphere are unchangeable in relation to annual and diurnal variation, so far they would tend to restrain any variation which might depend only on the varying temperature and state of the air; holding as it were the two sides of the variations, the increase and diminution of intensity, or the right and left hand in change of direction, nearer together than they otherwise would be.

2887. Further, if it be supposed that the whole of a hemisphere *is affected at once* in the same direction by change of temperature, it will *not be affected alike, but differently in different latitudes*, because of the difference in amount of that change.

2888. The difference of land and water (2880.) will still further break up any expected uniformity of the general result, and cause that certain parts of the cooling hemisphere shall increase in power more in proportion than other parts; and when these parts lie on opposite sides of the magnetic meridian of any given place, they would probably have power to cause an alteration in the declination of the needle at that place.

2889. As the annual changes of temperature are less at the equator than in parts more north or south, so there, probably, little or no annual variation would occur: none indeed as regards the varying temperature or expansion of the air, but only that portion which is consequent upon the alternate changes of the parts on its opposite sides (2884.).

2890. Another effect, which may be considered as an annual variation, but which is connected with the diurnal change, may be expected. As the daily changes in temperature of the atmosphere, influential upon a given place in north or south medium latitudes, are greater in extent in summer than in winter, so the corresponding magnetic variations may be expected to vary also, being larger in the northern hemisphere, when the sun is on the north side of the equator, and less when he is present in the southern hemisphere, and producing like correspondent change there.

2891. From a most important investigation by Colonel SABINE*, founded on the results of observations at Toronto and Hobarton, the facts appear to be that the magnetic intensity is greater in both hemispheres in those months which are winter in the northern hemisphere, and summer in the southern. Similar results are greatly wanted for other localities, and would show whether the different disposition of land and sea has anything to do with the question, or whether the results at Toronto and Hobarton are true exponents of hemispherical effects. Assuming Toronto and Hobarton as being such exponents, the dip in both hemispheres is greater (i. e. greater north dip at Toronto and south dip at Hobarton) in those months which are winter in the northern, and summer in the southern hemisphere. Whether there is any *annual* variation of the dip or total force in the equatorial parts of the globe is very important to determine. It would be well worth while to take up a station for the express purpose; the instruments are very simple, and the observations would require only a single observer. They are described in the paper referred to. Unfortunately such observations are not even made in Great Britain.

2892. The manner in which the diurnal variation may be produced or affected by the action of the sun on our atmosphere as the earth revolves in its beams, has been already generally referred to. The whole portion of atmosphere exposed to the sun receives power to refract the lines of magnetic force which traverse it, and the whole of that which covers the darker hemisphere assumes an equally altered, but contrary state, relative to the mean condition of the air. It is as if the earth were inclosed within two enormous magnetic lenses competent to affect the direction of the lines of force passing through them.

2893. I have already said that the action of the atmosphere thus affected might in some degree be compared at night time to that of an enormous, diffuse, and very feeble ordinary magnet, having the position that it would naturally take according to the line of dip, passing over us from east to west, and including us for the time within its influence: in the daytime the action would be like that of the similar journey, not of a corresponding magnet reversed in direction, but of a corresponding globe of diamagnetic matter (2821.). Assuming the maximum heat and cold to occur at midday and midnight, we might expect that the maximum effects would also occur near those periods as regards the variations of intensity (2824. 2866.); for, other things being the same, the central parts of the heated and cooled masses are those where the difference of intensity should be greatest.

2894. It might be expected that this variation in the *intensity* would be greatest at those parts of the globe over which the sun passes vertically, or nearly so; but that may depend upon two circumstances at least; first, whether the difference in the day and night temperature is greater there than at other places, because the extent of the variation may be dependent in part upon that difference; and next, whether the amount of effect to be expected is the same for the same difference in number of degrees of temperature at every part of the scale (2886.). If the conducting power of oxygen (2800.) should be found by future experimental measurements (2960.) to increase in a greater proportion for a fall of a given number of degrees at lower temperature than at high ones (including the effect of contraction for that fall (2861.)), then it may be that parts more distant from the sun will be more affected than those under it; or if the contrary be the case, less affected than otherwise would be expected.

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* On the means adopted for determining the Absolute Values, Secular Change, and Annual Variation of the Magnetic Force, Philosophical Transactions, 1850, p. 201.

2895. With regard to the daily variations, as respects the *direction* of the lines of terrestrial magnetic force, or the inclination and declination of the magnetic needle, the principles of the changes that may be expected to occur have been already referred to (2879.); and it remains for me to compare these expectations with a few simple cases of observation, in such a general manner as will tend to show whether the *direction* of action is, both in theory and fact, the same; and whether there is any probability that the effect has been assigned to its true cause; for this purpose I will confine myself entirely at present to a part of the daily variation, namely, the effect of the sun and air as the luminary arrives at and passes over the meridian.

2896. Profiting by the last volume which has issued from the powerful mind and careful hands of Colonel SABINE[*], I will take the case of Hobarton. The observatory there is in latitude 42° 52′·5 south, and longitude 147° 27′·5 east of Greenwich. The absolute declination is 9° 60′·8 east, and the dip is 70° 39′ south. In order to have the place of the sun and the time of maximum and minimum temperatures at hand, I have transferred the mean temperature for January (summer) for seven years, 1841–48, and the mean temperature for June (winter) for the same period, corresponding to every hour in the day and night, from pp. lxxxiv. and cviii. to fig. 10, Plate I., where the middle series of numbers represents the hours, the line next below them a base line of temperature at 30° FAHR., and the two curves still lower down the mean hourly temperature for summer and winter. The short lines show generally the direction of the needle east or west of its mean position, the upper end being of course the north extremity. The positions about noon are distinguished by full lines, being those required for more immediate illustration.

2897. The north end of the magnetic needle at Hobarton is most east at 2 o'clock, and most west about 21 o'clock. Being at the extreme west at the latter hour, it passes through the full range of variation, or to the extreme east in five hours, or by 2 o'clock, and then requires the remaining nineteen hours to return to the utmost west. The maximum east and west declination is at 2 and 21 o'clock for summer, and at 3 and 22 o'clock for winter. The vertical positions show at what hours the declination was 0, and correspond with SABINE's zero. From 21 to 2 o'clock the needle passes from one extremity of its variation to the other, the north or upper end traveling in the reverse direction to the sun, so that it and the sun cross the meridian together in opposite directions, nearly about or a little before noon. About 2 o'clock the needle is arrested, and after that time returns west, following the sun. It will be proper to state, that the north end of the needle, the motion of which has just been described, is the end towards the equator, and also, the upper end of a dipping-needle at Hobarton. This distinction will receive more significance presently.

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[*] Magnetical and Meteorological Observations, Hobarton, vol. i. 1850.

2898. Hence the cause which affects the needle appears to be far more powerful, and more concentrated in time when the sun is present than when he is away. In this there is accordance between the time of the effect and the time when the sun could exert most influence on those magnetic conditions of the atmosphere, which are for the present supposed to govern that effect.

2899. It will be seen by examination of fig. 10, that the time of maximum temperature is not when the sun is on the meridian, but two hours after it, both in summer and winter. But in reference to temperature and its effect on the magnetic condition of the air, and through that on the needle, it is not the local temperature which is supposed to influence the needle, but that which affects enormous masses of air, above as well as below, and of which the temperature at the spot, however important it may become when we can properly interpret it, gives us as yet little or no knowledge. Still there are some points on which temperature has a more direct bearing. Thus the amount of variation of temperature is in summer double what it is in winter, and the amount of variation in the declination increases in the same proportion (2890.). The minimum temperature in winter is later than in summer, and the extreme western declination of the needle is also later at the same period.

2900. The varying *direction* of the magnetic lines of the earth is made known to us by observations in two planes, one the horizontal plane, to which the position east and west is referred, constituting declination, and the other a vertical plane passing through the line of mean declination, and supplying observations of inclination. The direction of the line of force referred to this plane might change so as either to increase or diminish the inclination, and it does increase at some places for the same hour of local time for which it diminishes at others; thus it increases at Greenwich whilst it diminishes at St. Helena, which is nearly in the same meridian. At Hobarton it changes rapidly at the east and west extremes of the variation, *i. e.* about 2 and 21 o'clock. From noon it diminishes until about 3 o'clock; it then continues nearly the same in summer, when the variation is greatest until 18 or 19 o'clock, from that time it increases until about 22 o'clock, and is nearly a maximum from thence till noon. Hence it will be understood, that the inclination is generally greatest during the rapid journey of the north end of the needle from west to east between 21 and 2 o'clock, and least in the other or prolonged half of the journey; and though this is partly broken up in the night effect, to be considered hereafter, still as a general result it always appears.

2901. All this may be roughly represented by fig. 11 (2909.), in which E.W. represents the path of the sun between the tropics as he comes up with the hours 21^h, 22^h, &c. in his daily journey, and *e* the path described by the north or upper end of the needle, freely suspended at Hobarton, and therefore showing both declination and inclination, *i. e.* the whole direction. Looking down upon such a needle, its upper end will take the course indicated by the arrow, and its position at any given hour is shown sufficiently by the leading lines.

2902. This relation of the motion of the needle to that of the sun has long been known; it has great significance in relation to my hypothesis of the physical cause of these variations. As regards the part of the action which I am considering, it is as if the pole of a magnet came on with the sun, of like nature to the upper end of the Hobarton needle, and at first drives that end west. Towards 19 o'clock the tendency westward diminishes, but the tendency south increases. At 21 o'clock, the increase in the sun's power, acting not directly from the sun but from a region in the atmosphere beneath it, is not sufficient to compensate for his more unfavourable position; the earth's force brings the needle back as regards declination, and then it passes eastwards, but the southerly motion or inclination still increases; about 24 o'clock, or noon, the sun is as to east or west declination indifferent, but powerful in southern action, making the inclination then, or soon after, a maximum. Then as the sun goes west of the needle, its power in driving the pole behind it eastward, will increase for a time, whilst the power producing inclination will diminish, until at 2 or 3 o'clock the earth's force will regain preponderance as the sun's power diminishes by distance, and the needle will return towards its least dip and mean inclination.

2903. All this may be represented experimentally by carrying a magnetic pole north of the dipping-needle, so as to represent the place of the sun-heated air to Hobarton, provided that pole be of the same kind as the north or upper pole of the needle. I have already stated (2877. 2863.), that when a portion of air is heated in a field of magnetic power, it loses in magnetic conduction power, and if in association with air less heated deflects the lines, assuming the state which I have distinguished as that of diamagnetic conduction polarity; then presenting the very polarity, or rather the very inflection of the lines of force, which would affect the needle, as it is affected. As the sun rises and passes north of such a place as Hobarton, the atmosphere under his coming influence becomes more and more heated and expanded; and referring to the model globes of air (2864. 2877.), it is as if such a warm mass passed with the sun through all the regions of the equator, extending also far north and south of it; and having Hobarton within its influence, produced the effects there observed.

2904. In such a view one sees a reason for the short time occupied in the return of the needle from west to east as the sun passes immediately over its meridian, and for the long time during which it is passing from east to west as the influence of the sun is slowly withdrawn, and then again slowly renewed during the remaining part of his journey, exception being made for the present of the paramagnetic effects due to cold.

2905. I will now consider the Toronto case of diurnal variation as it is presented to us in the volume of magnetical observations, issuing from the same authority and hands as the former volume*, and also in further observations down to 1848, sent to me by the kindness of Colonel SABINE. The position of the observatory is in lat. 43° 39′ 35″ N. and long. 79° 21′ 30″ W. The absolute declination is 1° 21′ 3″ W., and the mean or absolute dip is 75° 15′ N., so that as regards Hobarton it is on the other side of the equator, and nearly on the other side of the world. The result for the months of June and December are placed in a diagram corresponding to that for Hobarton (2896.), employing the Toronto time for the hours, Plate I. fig. 12.

2906. The north end of the needle is that universally referred to in speaking of the declination; its course at Toronto, during the immediate sun effect, is as follows:—Having gradually moved east from 16^h, it is at extreme east at 20 o'clock, and then returns from the east to extreme west in six hours, after which it moves eastward from the sun. But if we convert this into the motion of the equatorial extremity of the needle, for that is the *upper* end if the needle be free, and concerns us most in the comparison with Hobarton, then it will be seen that this end is most west at 19^h or 20^h; and leaving that position at that hour, it travels quickly eastward, passing through the full range of variation or to extreme east in six hours, or until 2^h, and then returns, following the sun.

2907. Looking at these results, I might repeat the words used in illustration of the Hobarton effects, but for the sake of brevity will simply refer to them. As before, the amount of variation in the declination is in summer double what it is in winter. The difference of temperature is three times greater. The extreme west and east declination is both in summer and winter at 20 and at 2 o'clock, so that the magnet holds to the time in both seasons; but the maxima and minima of cold, as shown before, vary in the two seasons, for the former is at 4 o'clock in summer and 2 in winter, whilst the latter is at 16 o'clock in summer, and 20 o'clock in winter. But this is a variation with consistency; for it will be seen by a moment's inspection, that in winter the maximum of heat has moved towards the time of most powerful action in the one direction, and the minimum has moved towards it in the other. The passage of the sun, therefore, over the meridian, and the period of rapid motion of the needle from west to east, still coincide.

2908. The other element of direction is the inclination. Its variation is very small, but changes thus. A principal maximum dip occurs at 22 o'clock, and the extreme minimum dip at 4 o'clock.

2909. So all the effects may again be generally represented by an ellipse (fig. 13)

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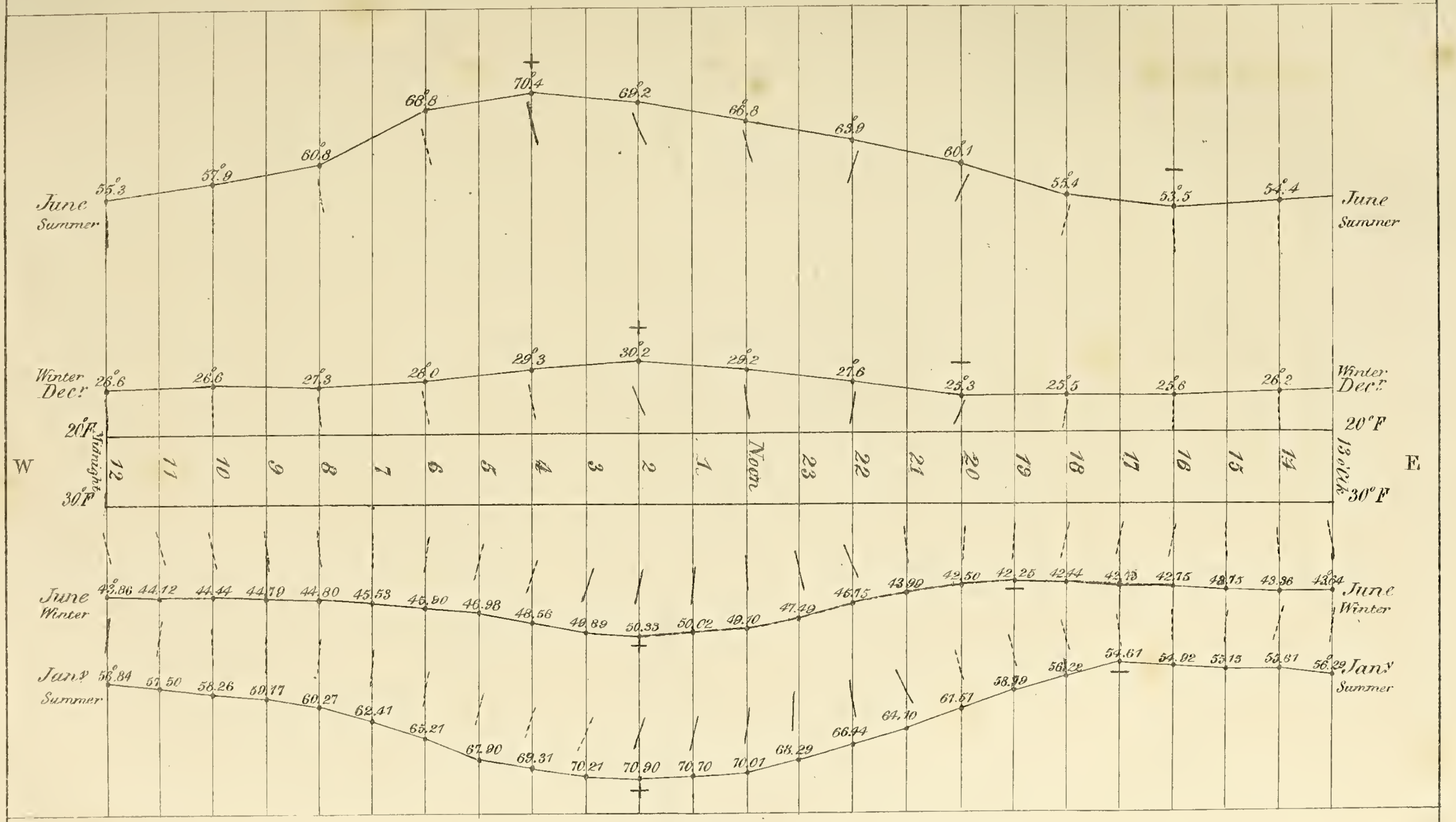
* Magnetical and Meteorological Observations. Toronto, 1840, 1841, 1842, SABINE.

Fig. 12.

Lat 43° 39' 35" N Toronto *Long: 79° 21' 30" W*



Lat 42° 52'.5. S Hobarton *Long: 147° 27'.5 East*
Fig. 10.

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as they were for Hobarton; and I may refer to the words then used, substituting

Fig. 13.

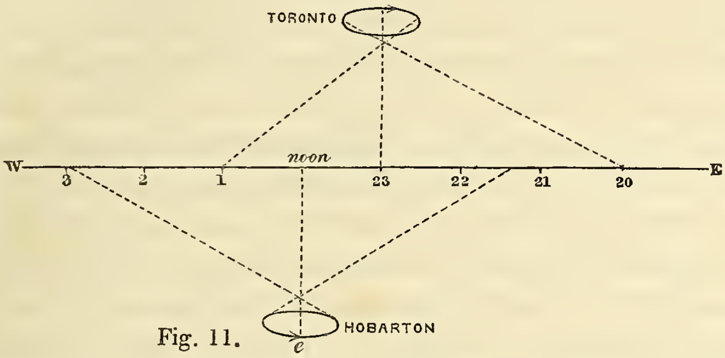

Fig. 11.

Toronto for Hobarton, and north for south (2901.). As the sun comes up from the east in his course between the two places, he drives, by the altered atmosphere beneath him, the upper ends of their needles before him, and outwards from the line of his path, as if he were a north pole to the Hobarton magnet, and a south pole to the Toronto magnet. By 22 o'clock, the earth's force, and the action of the air due to the sun's position, permit a return to the east, though the inclination for a time increases (2902.); both swing rapidly round from west to east as he passes over the meridian, and then having attained their maximum position eastward, soon follow after him under the influence of the earth's force, less and less counteracted by the retreating sun. So striking is the similarity between Hobarton and Toronto, that Colonel Sabine has already especially distinguished and described it*, and has shown, that, laying down the direction of motion in both cases by curves, and bringing the two curves together by their faces, they coincide almost exactly, with this single difference, that the Hobarton changes precede those at Toronto by an hour, or rather more, of local time.

2910. We cannot represent this day effect experimentally upon two such needles as those at Hobarton and Toronto by one pole of a magnet, though we can do it with each separately with different poles: but we see at once from the hypothesis, the reason why the sun acts in this manner (2877.), and how it is that the region of influential atmosphere that accompanies him in his journey round the globe, acts with one effect in the northern latitude and another in southern positions (2903.). The reasons also for the short time of the day journey and the lengthened period of the night return (2904.), are manifest. The occurrence of disturbances or secondary waves of power in the night time, and the condition both of the chief variation and the subordinate oscillations in summer and winter, will be considered hereafter.

2911. *Greenwich.*—The following results are taken from the volume of Greenwich Observations for 1847. The latitude is 51° 31′ N., and being removed nearly 80° in longitude from Toronto, the station is well contrasted with it and also with Hobarton.

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* Hobarton Magnetical Observations, 1850, p. xxxv.

The mean declination is 22° 51′ 18″ W., and the mean inclination is 69° N. As it is the upper end of the dipping-needle which we have to consider for the purpose of a ready comparison with the sun's observed day action (2906.), I will describe that part of its course and place for Greenwich time which concerns us now. Moving westward before 19^h and 20^h, it then returns towards the east, and in six hours, or by 1^h or 2^h, has completed the great sun swing, after which it returns west, following the luminary. The vertical force is given as greatest between 3 and 4 o'clock, and least between 11 and 13 o'clock. The south end of the needle therefore is more upright at the former time and less at the latter; and as the latter occurs during the prolonged return part of the journey from east to west, including the night hours, so we perceive that the upper end of the needle performs its daily journey in an irregular closed curve, which the ellipse for Toronto, fig. 13 (2909.), may generally represent; it passes from east to west slowly during the night hours, approaching the equator at the same time, and then it returns from west to east with far greater rapidity, performing this part of its journey at a greater distance from the equator and nearer to the pole.

2912. *Washington, U.S.*—Latitude 38° 54′ N.; longitude 77° 2′ W.; the mean declination 1° 25′ W.; the mean dip 71° 20′ N. The south or upper end of the needle is in the morning at extreme west, about 20 to 22 o'clock, and at extreme east about 2 o'clock; it then returns slowly west, with the night action as in former cases, regaining extreme west at 20 to 22 o'clock. This is exactly the same movement for declination, in relation to the place of the sun, as for the former localities. I have not the variation of the dip, but theory would lead one to conclude that it is greatest between 22 and 2 o'clock, and least in the evening and night time. The total amount of declination variation is greatest in summer, as before, being 9′·87 in July and only 4′ in December. The greatest difference in the earth's temperature is also in July, being then nearly 20° Fahr., whereas in December and January it is only 10° Fahr. The shortest period between the extreme temperature, including therefore the quickest change of temperature, is from 16 or 18 to 2 o'clock, and consequently includes noon. All these conditions combine to produce the greatest magnetic action, and it is in the direction pointed out by the hypothesis.

2913. *Lake Athabasca.*—Latitude 58° 41′ N.; longitude 111° 18′ W. of Greenwich; mean declination 28° E. The observations are only for five months, but as the position is in a high latitude and may be important for future considerations, I give the results here. The extreme western position of the upper end of the needle is about 17 or 18 o'clock, and its extreme eastern position about 1 or 2 o'clock; so that, as far as declination is concerned, the action of the sun and atmosphere is as in former cases. The amount of declination variation is very great, being in October 21′·32; in November 10′·8; in December 9′·78; in January 16′·29, and in February 14′·87.

2914. *Fort Simpson.*—Latitude 61° 52′ N.; longitude 121° 30′ W. of Greenwich;

mean declination 38° E. These observations are only for two months, *i. e.* April and May 1844. The extreme western place of the upper or south end of the needle was at 19 o'clock, and its extreme eastern position at 2 o'clock. The result therefore is in perfect accordance with the preceding observations and conclusions. The amount of variation, as given in the horizontal plane, is very large, being 36'·26 in April and 32' in May.

2915. *St. Petersburgh.*—Latitude 59° 57' N.; longitude 30° 15' E. of Greenwich; mean declination 6° 10' W.; the dip 70° 30' N. The observations are the mean of six years, and show that the upper end of the needle is extreme west in regard of noon, about 19^h and 20^h for the months of March to August, and that for the other months there is a western position about the same hours. The extreme east position is, for *all* the months, about half-past 1 o'clock, so that the sun's effect in passing over at the noon period is as in former cases. The greatest amount of variation is 11'·52 in June; in winter it dwindles away to as little as 1'·77. From theory, the dip may be expected to increase during the day hours and diminish at night.

2916. Thus these cases, which, including the chief feature of diurnal variation and sun action, were selected as a first and trial-test of the hypothesis, join their evidence together, as far as they go, in favour of that view which I am offering for their cause; nor have I yet found any instance of even an apparent contradiction in regard to the sun action. They assist the mind greatly in forming a precise notion of the manner in which the influence of the sun and air is supposed to act, not only in similar cases, but in respect of other consequences, *i. e.* in all that properly comes under the term of atmospheric magnetism; I will therefore now restate more particularly the principles which, according to the hypothesis, govern them, in hopes that I may be fortunate enough to assist in developing by degrees the *true physical cause* of the magnetic variations in question.

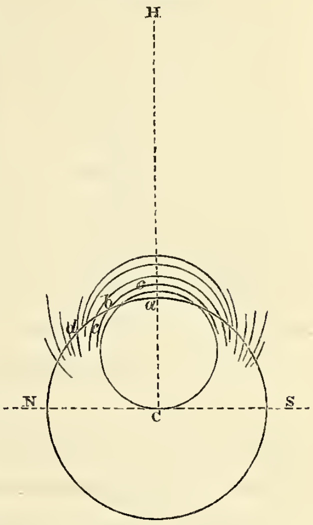
2917. Space, void of matter, admits of the transmission of the magnetic force through it (2787. 2851.). Paramagnetic and diamagnetic bodies either increase or diminish the degree in which the transmission takes place (2789.). This, their influence, I have expressed, for the time, by the phrase of magnetic conducting power, and I think have given sufficient first experimental evidence of the existence of the power and its effects in disturbing the lines of magnetic force (2843.). The atmosphere is, by the oxygen it contains (2861. 2863.), a paramagnetic medium, and has its conducting force greatly diminished by elevation of temperature (2856.) and by rarefaction (2782. 2783.), as has also been fully proved by experiment. The sun is an agent which both heats and rarefies the atmosphere, and in its diurnal course, the place of greatest heat and rarefaction must, speaking generally, be beneath it. The irregularities in the condition of the earth's surface and other causes do produce local departures from an exact relation of place, but they probably disappear partly, if not altogether, in the upper regions of the air.

2918. Assuming that *the air under the sun* is most changed magnetically, and confining the attention to a spot where the sun is vertical, for the purpose of considering the condition of the atmosphere there and at other parts in relation to it, the supposition of a globe of air over the spot will of course find no fit application (2877.). We are first to suppose the sun far away and the atmosphere in a mean state as to temperature, and then consider the sun as present in the meridian of a given place; and it is *the degree of alteration* in temperature and expansion of the air beneath and around the place of the sun, and the manner in which the change comes on and passes away, which concerns us. In relation to the surface of the earth, that alteration will be greatest somewhere beneath the sun, and will diminish in every direction around, becoming nearly nothing as to direct action at that part or circle of the earth where the sun's rays are tangent. In relation to elevation, it is a question yet whether the effect is greatest in amount at the surface, diminishing upwards. As regards the atmosphere, it must of course end with it, though as respects space itself (2851.), a reservation thought may arise. With regard to any alteration occasioned by the sun's influence in the opposite hemisphere, though there is none produced directly, yet indirectly there is that due to the falling of the temperature of the air, from the condition to which the sun, whilst above the horizon, had brought it. This change must be more tardy, irregular and disturbed, by local and other circumstances, than the opposite alterations produced by the direct influence of the luminary, and is that which occasions, by the hypothesis, the second maximum or minimum or other recurring night actions, made manifest by the needle in the hours when the sun is away.

2919. The lines of force which issue from a magnet are, as it were, located and fixed by their roots in a way well understood experimentally by those who have worked upon this subject. In the same manner the lines which issue from the earth more or less suddenly, according to the amount of inclination, are held beneath by a force of location; and because of the unchanging action of the earth in respect of atmospheric effect, are restrained more or less from alteration beneath during the changing action of the atmosphere. This fixation in the earth is a chief cause of certain peculiarities in the atmospheric phenomena as we observe them; and is productive of that rotation of the line of force about the mean position which we have already considered during the sun swing, and shall meet with again under the action of cold air. This condition of fixation at the lower parts of the lines of force occurs at every station where there is any dip at all, and gives for each the point of convergence round which the motion of the upper end of the needle takes place (2909. 2932.).

2920. So the atmosphere, under the influence of the sun, lies upon the earth altered most at the part beneath the luminary. It has received power to affect the lines of magnetic force differently to the manner in which it affected them in the sun's absence. It has become a great magnetic lens, able to refract the lines, and the manner in which it does so appears to be of the following nature. All the lines passing through this heated and expanded air, surrounded by other air not so much heated, will, because of its being a worse magnetic conductor than the latter (2861. 2862.), tend to open out (2807.); and the mass of heated air, as a whole, will assume the condition of diamagnetic polarity. If, therefore, for the sake of simplicity, the magnetic and astronomical poles of our earth be supposed as coincident, and fig. 14 represent a section taken through them and the place of the sun, then N and S will be the magnetic poles, and the different curves cutting the outline of the circle will sufficiently represent the course of the magnetic lines as they occur at or about the surface of the earth, H being the sun, and *a* the place immediately beneath it, which is also coincident with the magnetic equator. By this diagram we shall have an illustration of the hypothetical effect on the inclination of the needle.

Fig. 14.



2921. Considering the point *a* first, and assuming as yet that the maximum of change in the air is always at the surface of the earth, we shall find that there the lines of force will open out, preserving in some degree their parallel or concentric relation. Consequently a magnetic needle, free to move in every direction, and therefore taking up its position *in* the line of force, ought not, if placed at this spot, to be altered in its position. It ought to show perhaps a diminution of magnetic force transmitted through that spot; but, for the reason before given (2868.), I conclude it would indicate a greater intensity, the increased power thrown upon it through the diminution of the conducting power of the air in that place causing it to act as a more powerful needle.

2922. Proceeding to a point *b*, there the lines of force have dip. The same physical effect will be produced upon them here as before, *i. e.* the portions in the atmosphere will open out; but neither here nor in the former case will they continne to have the same curvature as before, for towards and in the earth, where they have their origin, they are restrained more or less from altering by the unchanging action of the earth (2919.); whilst at their more advanced parts, as at *c*, they enter into portions of the atmosphere which are nearer to the most intense lines of solar action, H C, probably also into the region of most intense action, and also into space, circumstances which cause more displacement of the lines, tending to separate by the tension of the parts altered in the air, than can happen *in* the earth (2848.). So the magnetic line of force at *b* will not move parallel to itself, but being inclined a certain degree to the horizon, when in the normal condition, will be more inclined, *i. e.* will have more dip given to it by the presence of the sun. This is the fact made manifest by the needle when indicating the position of the line as to inclination (2908.) at Hobarton, Toronto or elsewhere, by the motion of its upper end; for it is manifest that whatever happens on one side of the place of the sun and magnetic equator, when, as in our supposition (2920.), they coincide, will happen on the other.

2923. The case may be more simply stated, for the facility of recollection, by saying that the effect of the sun is to raise the magnetic curves, over the equatorial and neighbouring parts, from their normal position, in doing which the north and south dip are simultaneously affected and increased.

2924. At the place *d* like effects on the inclination must be produced, and theoretically it should be affected in the same direction even at N. and S. At the point *a* the inclination is supposed to be not at all altered, but going either north or south, the changes appear and increase. It is not probable that the maximum alteration will be at N. or S., but the latitude where it will occur must depend upon the many conjoined circumstances that belong to the case of a globe round which a magnetic lens, such as I have endeavoured to describe, is continually revolving.

2925. Instead of assuming that the sun is at H, let us suppose that we are looking at the diagram in a vertical position and towards the east; the sun coming up from the east and passing over our heads, and bringing with it that condition of our atmosphere which is the cause of the change. As it does so, all the magnetic curves would rise; the inclination would increase at *b*, *d*, and every place where there was any beforehand, in opposite directions on the two sides of *a*; this would go on until the sun was in the zenith, and then as it passed away and sank behind us, the lines would draw in again and the dip diminish to what it was at first. The maximum of dip would be when the sun was near the zenith, and the minimum when he was quite away.

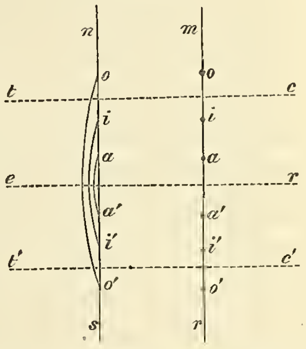
2926. But if the resultant of force be above in the atmosphere (2937.), which is by far the most probable, as it is the whole atmosphere which acts by heat diamagnetically, then the results would be modified; for if over *a* the lines of force might be *depressed*, and the inclination there would be diminished; at *b* it might not for the moment be affected; whilst in higher latitudes it would be increased, according as the line of force from the resultant in the atmosphere, wherever that might be, fell outside of the angle formed by the inclination with the horizon of a given place or within it. St. Helena, the Cape of Good Hope and Hobarton, furnish instances of the three cases.

2927. At the same time the total force would undergo a change in its amount; that transmitted through a given space would be least when the sun was in the zenith, and most when he was away (2863.). The total variation in the force should be greatest at *a*, and diminish from thence towards north and south. The daily variations of the inclination are so imperfectly known to us at present, that we cannot say how far the natural changes will accord with these expected variations, but as far as the observations go they agree with the theory.

2928. If the sun, instead of being over the equator, is at a tropic and so vertical, for instance over *b*, then the effects will be modified; and the resultant still being assumed as above, the lines of force which before were not affected, may be expected to descend and lessen the inclination, whilst other lines in higher latitudes, which before were increased in inclination, may now be but little affected, and other lines in still higher latitudes have, as before their inclination, increased. On the other side of the equator, the tendency of the lines would be to increase in inclination.

2929. Proceeding to that part of the expected change of position of the free needle which produces variations of *declination*, let *e r* in fig. 15 represent the sun's path in the equator, and *t c*, t' c' the same at the tropics; let *m r* be a magnetic meridian, and $a\ a'$, $i\ i'$, $o\ o'$ places of equal north and south inclination on opposite sides of the equator. The curves of magnetic force seen in front in fig. 14, are now in the plane of the magnetic meridian, but may be considered as rising on opposite sides of the equator and coalescing over it. If the air on all sides were in its mean condition and the sun entirely away, these curves would be in the vertical plane *m r*; or if the sun near midday was so placed that the resultant of the heated and changed atmosphere was in the meridian *m r*, though effects of inclination would occur (2922.), still the curves would remain in the same vertical plane. But if the resultant were either to the east or the west of *m r*, variations of declination would be produced. For suppose the sun to be advancing from the east or *r*; because it gives the air a diamagnetic condition, the lines of force would tend to expand (2877.), and therefore move westward, as represented in the meridian *n s*; and the deflection caused thereby would be greatest upon the surface of the earth, because it is there that the curves as they enter the earth are held and restrained in respect of their normal position (2919.). As the warmed atmosphere came on, the western deflection would increase to a certain extent, and then diminish to nothing when the resultant was in the meridian; but as the latter passed on, the deflection would grow up on the eastern side of *n s*, and, after attaining a maximum, would diminish and cease as the warm air retreated.

Fig. 15.



2930. If the sun's path was in the northern tropic, *t c*, and the resultant in the atmosphere therefore to the north of the stations *a* or *i*, though that would make a difference in the amount of the declination variation, it would not alter its *direction*, for still the curves $a\ a'$ and $i\ i'$ would bear to the west as the sun came up, and would be on the meridian when the resultant was there also. There would be more effect produced at *i* than at i', but the contrary character of the dip, in respect of the sun's place, would not alter the direction of the declination variation.

2931. A cold region of air acting, as at the coming on of night, upon the lines of magnetic force of the earth, would, by virtue of its paramagnetic character (2865.), produce corresponding effects both of inclination and declination, but in the contrary direction.

2932. Thus the lines of force which issue from the earth at all places upon its surface where there is any dip, will, by the hypothesis, under the daily influence of the sun, describe by their ascending parts a closed curve or irregular cone, the apex of which is below. As a fact this result is perfectly well known, but its accordance with the hypothesis is important for the latter. The mean position of the free needle will be in the axis of this curve or cone, and its return, either in declination or inclination, to the mean is an important indication of the amount and position of the variable forces which influence it at such times.

2933. My hypothesis does not at all assume that the heated or cooled air has become magnetic so as to act directly on the needle after the manner of a piece of iron, either magnetically polar or rendered so under induction. There is no assumed polarity of the oxygen of the air other than the conduction polarity (2822. 2835.) consequent upon a slight alteration of the direction of the lines of force. The change in the magnetic conducting power causes this deflection of the lines; just as a worse conductor of heat introduced into a medium of better conducting power disturbs the previous equable transfer of heat, and gives a new direction to that which is conducted; or as in static electricity, a body of more or less specific inductive capacity introduced into a uniform medium disturbs the equable lines of force which were previously passing across it.

2934. The sole action of the atmosphere is to bend the lines of force. The needle being held by these lines and, when free, being parallel to them, changes in position with the changes of the lines. It is not necessary even that the lines, which are immediately affected in direction by the altered air, should be those about the needle, but may be very distant. The whole of the magnetic lines about the earth are held by their mutual tension in one connected sensitive system, which has no sluggishness anywhere, but feels in every part a change in any one particular place. There may be, and is continually, a new distribution of force, but no suppression. So when any change in direction happens, near or distant, the needle in a given place will feel and indicate it, and that the more sensibly according to the vicinity of the place and the kind of change induced; but the disposition of the *whole* system has been affected at the same moment, and therefore all the other needles will be affected in obedience to the change in the lines of force which govern them individually.

2935. The needle is a balance on which all the magnetic power around a given locality fastens itself, even to the antipodes, and it shows for each place every variation in their amount or disposition, whether that occurs near or far off. Its mean position is the normal position; and as regards atmospheric changes, the fixation of the lines of force in the earth (2919.) is that which tends to give the lines a standard position (exclusive of secular changes), and so bring them and the needle back from their disturbed to their normal state. Hence, whilst considering the causes which disturb either the declination or the inclination, arises the importance of keeping in mind the mean position or place of the needle (2932.), and not merely the direction in which it is moving.

2936. So the well-known action of the sun on the needle is, by my hypothesis, very indirect; the sun at a given place affects the atmosphere; the atmosphere affects the direction of the lines of force; the lines of force there affect those at any distance, and these affect the needles which they respectively govern.

2937. I have, for the sake of convenience in considering a special action of the atmosphere, spoken of the resultant in the atmosphere dependent on the sun's presence; and will do so a little while longer without implying any direct action of this resultant, or that portion of air which yields it, upon the needle (2933.), for the sake of considering at what probable height it is situated in the air. That it cannot be on the surface of the earth, is shown by the depression of the lines and diminution of the dip at St. Helena and Singapore during the middle of the day; and that it is not even under the sun, is shown by the manner in which the greatest action precedes, in some degree, the sun, as at Hobarton and Toronto, and other places by different amounts of time; neither the time when the sun is on the meridian, nor the time when the observed temperature is highest (for that is after the sun), is the time of greatest action, but one before either of these periods. The changes in the temperature of the air produced by the sun, will not take place below and above at the same time. The upper regions of the atmosphere over a given spot are affected by the sun at his rising and afterwards, before the air below is heated; and therefore the effect from above would be expected to precede that below. The temperature observed on the earth does not show us, for the same time, the course of the changes above, and may be a very imperfect indication of them. The maximum temperature below is often two, three, or four hours after the sun, whereas, whatever heat the sun gives by his rays directly to the atmosphere, must be acquired far more rapidly than that. It is very probable, and almost certain, that at 4 or 5 o'clock A.M. in the summer months, the upper regions may be rising in temperature, whilst on the surface of the earth, through radiation and other causes, it is falling. The well-known effect of cold just before sunrise in some parts of India, and even in our country, is in favour of such a supposition. We must remember that it is not the absolute temperature of the air at any spot that renders it influential in producing magnetic variations, but the *differences* of temperature between it and surrounding regions. Though the upper regions be colder than the lower, their changes may be as great or greater; they happen at a range of temperature which is probably more influential than a higher range (2967.); and, what is of importance, they occur more quickly and directly upon the presence of the sun. The quantity of heat which the atmosphere can take directly from the sun's rays, is indicated by the different proportions we receive from him when he is either vertical or oblique to us, and so sending his beams through less or more air; and when he has departed, the upper parts of the air are far more favourably circumstanced for rapid cooling by radiation than the portions below. So that the final changes may be as great or greater than below, and we may learn little of them, or their order, or time, by observations of temperature at the earth's surface. In addition therefore to observations of magnetic effect, as depression of the lines of force at St. Helena, &c., there are apparently reasons deducible from physical causes, why the chief seat of action should be above in the atmosphere.

2938. In the midday effect the upper end of the needle passes the mean position

(2935.) on its return to the east generally before the sun passes the meridian going westward. At Toronto it is about an hour in advance; at St. Helena and Washington an hour and a half; at Greenwich and Petersburgh two hours; at Hobarton and the Cape of Good Hope the passage is about noon. Such results appear to indicate that the place of maximum action is in advance of the sun; and it probably is so in some degree, but not so much as at first may be supposed, as will appear I think from the following considerations.

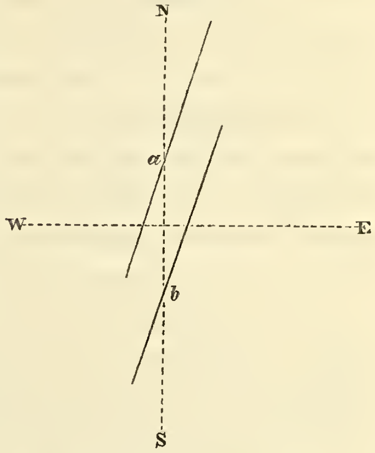
2939. The precession of the time of maximum action may depend in part upon some such condition as the following. As the sun advances towards and passes over a meridian, the air is first raised in temperature and then allowed to fall, and these actions produce the differences in different places on which the magnetic variations depend. But they depend also upon the *suddenness* with which or the vicinity at which these differences occur. Thus two masses of air, having equal differences of temperature, will affect the lines of force more if they be near together, and to the needle, than if they be far apart. And again, if a body of air were of a certain low temperature at one part, and, proceeding horizontally, were to increase rapidly to a certain high temperature and then diminish slowly to the first low temperature, such a body passing across a set of lines of magnetic force would affect them in opposite directions at the fore and after part; but it would affect them most on the rapidly altering side.

2940. Now the air as heated by the sun must be in this condition. According to analogy with solid and liquid bodies, being exposed to heat and then withdrawn, the changes of temperature that it would undergo would be more rapid in the elevation than in the falling, and so the changes in the preceding would be more rapid than in the following parts. To this would be added the effect of the atmosphere warmed by the earth; for as that is slower in attaining heat, as is shown by the time of maximum temperature, so its effects being gradually communicated to the air above, as the sun passed away, would tend to retard its fall and enlarge the difference already spoken of. Applying these considerations to the natural case, the strongest effect and the greatest variation should be towards the west, and the following or lesser action towards the east of the sun; and the mean condition of the needle for the whole change would be in advance of that body.

2941. Mr. Broun has made observations of the daily variation at different heights, namely, at Makerstoun and the top of the Cheviot Hills, where the height differs by nearly half a mile, and finds, I believe, no difference in the intensity, but that the progress is *first* at the higher station. It would be very interesting to have an observatory up above, but to give the results required it should have air and not solid matter beneath it.

2942. There is another circumstance which importantly influences the *times* of the passages of the declination variation. If two places north and south of the equator have equal dip and contrary declinations, *i. e.* if both their upper ends point east or west, then the effects ought to correspond and form a pair. But if both have east or west declination, according to the usual mode of marking this effect by the north end of the magnet, then the variations already described should come on as the sun passes midway between them, but there should be a difference in *time*. As the luminary appears and approaches, the needles *a* and *b* (fig. 16) will most probably be affected together; but, as he draws nigh, if the places have eastern declination, the one that is south will be soonest affected, and for the time most strongly, but will in a period more or less extended, be followed by the corresponding action at the other place. For as each needle will have returned from the first half of its series of changes to 0° by the time the sun is on its magnetic meridian, and as it will arrive at this meridian, as regards the south needle, before it does so for the north needle, so the south magnet should precede the other in its changes. If the declination of both were westerly, then the north needle would precede the south.

Fig. 16.



2943. The hypothesis advanced, besides agreeing with the facts regarding the direction of the needle's motions, as is the case generally, and if my hopes are well-founded, will be the case also in more careful comparisons; should also agree in the *amount* of force required for the observed declinations at given hours. I have endeavoured to obtain experimental evidence of the difference of action of oxygen and nitrogen on needles subjected to the earth's power, but have not yet succeeded. This however is not surprising, since a saturated solution of protosulphate of iron has failed under the same circumstances. More delicate apparatus may perhaps yield a positive result.

2944. That small masses of oxygen should not give an indication of that which is shown by the atmosphere as a whole is not surprising, if we consider that the mass of air is exceeding great, and includes a vast extent of the curves on which it, by the hypothesis, acts; and yet that the effect to be accounted for is exceeding small. The extreme declination at Greenwich is 12′, equal to about 4′ 24″ of east and west alteration on the free needle, so that that is the whole of what has to be accounted for. One could scarcely expect such an effect to be shown by small masses of oxygen and nitrogen acting on only a few inches in length of the magnetic curves passing through them, unless one could use an apparatus of extreme and almost infinite sensibility; but from what I have seen of oxygen when compared at different degrees of dilution (2780.), or at different temperatures (2861.), I am led to believe that the effects on it produced by the sun in the atmosphere will ultimately be found competent to produce these variations.

2945. Where the air is changed in temperature or volume, there it acts and there it alters the directions of the lines of force; and these by their tension carry on the effect to more distant lines (2934.), whose needles are accordingly affected. The transferred effect will be greater or less according as the distances are less or greater, and hence a change near at hand may overpower that at a distance, and a cloud close to a station may for the moment do more than the rising sun. These are the irregular variations; and the extent of their influence is well shown by the photographic records of Greenwich and Toronto. The volume of Greenwich Observations for 1847 contains a photographic record of the declination changes, February 18—19, 1849. Between 6 and 7 o'clock there is a variation of 16′ occurring in 18 minutes of time, or at the rate nearly of 1′ for each minute of time. The course of the mean variation for the same date and time is 1′·95 in two hours, or at the rate of 1 second for each minute of time, so that the irregular variation (which may be considered as a local variation in respect of the sun's power for the time) is sixty times that due to the effect of the great resultant; moreover it was in the reverse direction, for the temporary variation was from east to west, whilst the mean variation was from west to east.

2946. Another mode of showing how much the action of nearer portions of the atmosphere overpower and hide the effect of the whole mass, is to draw the line of mean variation for the twenty-four hours through such a photographic record as that just referred to, and then it will be seen in every part of the course how small the mean effect on the needle is, compared to the irregular or comparatively local effect for the same moment of time. The magnet with which these observations were made, is a bar of steel 2 feet long, 1½ inch broad and a quarter of an inch thick, and therefore not obedient to sudden impulses; it is probable that a short, quick magnet would show numerous cases in which the irregular variation would be several hundred of times greater than the mean. Still all these irregularities and overpowering influences of near masses are eliminated by taking the mean of several years' observation, and thus a true result is obtained, to which the hypothesis advanced may be applied and so tested.

2947. Returning for a short time to the annual variation (2882.), I may observe, that it has been a good deal considered in discussing the daily variation. The arrangement of the magnetic effects by Colonel Sabine at Hobarton, Toronto, St. Helena and elsewhere, into monthly portions, proves exceedingly instructive and important, especially for places between and near the tropics. It supplies that kind of analysis of the annual variation which is given by the hours for the daily variation. Every month, by a comparison of its curve with those of other months, tells its own story, at the same time that it links its predecessor and successor together.

2948. I shall have occasion to trace these monthly means hereafter; but in the meantime refer to the effect of the sun's annual approach and recession indicated by these means, as according with the hypothesis in respect of near and distant actions (2945.). Hobarton and Toronto are in opposite hemispheres, so that the sun whilst approaching one recedes from the other, and the amount of variations therefore changes in opposite directions. Below is the average for each month, derived in the case of Hobarton from a mean of seven years, and in that of Toronto from a mean of two years.

	Hobarton. Lat 42° 52′·5 S.	Toronto. Lat. 43° 39′·35 N.
	′	′
January	11·66	6·51
February	11·80	6·40
March	9·50	8·50
April	7·26	9·52
May	4·56	10·34
June	3·70 Winter	11·99
July	4·61	12·70 Summer.
August	5·89	12·68
September	8·24	9·72
October	11·01	7·59
November	12·05 Summer	5·75
December	11·81	4·47 Winter.

The two stations are in latitudes differing only 47′ from each other; and the extreme difference of the atmospheric effect between summer and winter differs as little, being at one, Hobarton, which has the highest latitude, 8′·35, and at Toronto 8′·23.

2949. According to Dove, the northern hemisphere is warmer in July than the southern hemisphere by 17°·4 Fahr., and colder in winter by only 10°·7; the numbers being as follows:—

July.	Northern hemisphere 71°·0	62°·3	the whole globe.
	Southern hemisphere 53·6		
January.	Northern hemisphere 48·8	54°·15	the whole globe.
	Southern hemisphere 59·5		

The mean for the whole year is 59°·9 for the northern hemisphere, and 56°·5 for the southern. Therefore, as Dove further shows, the whole earth is in July, when the sun is shining over the terraqueous parts, 8° higher in temperature than in January, when it is over the watery regions: and from the influence of the same cause, the mean of the southern hemisphere is 3°·4 below the mean of the northern half of the globe. The difference between January and July is for the northern hemisphere 22°·2, and for the southern only 5°·9. These differences are so peculiar in their arrangement and so large in amount, that they must have an effect upon the distribution of the magnetic forces of the earth, but the data are not yet sufficient to enable one to trace the results. Sabine indicates a probability from his analysis of observations, that the sum of the earth's magnetic force is increased in intensity when the sun is in the southern signs, *i. e.* in our winter (2891.). I should have expected from theory that such results would have been the case, at least in those parts where the dip was not very great; because a colder atmosphere ought to conduct the lines of magnetic force better, and therefore the systems round the earth ought at such a time to condense, as it were, in the cooler parts. It would be doubtful, however, whether the needle would show this difference, because the lines of power would not be restrained above, as in the case formerly supposed (2922.), but could gather in from space freely. From what has been said, however, it will be evident that such a conclusion can only be drawn with any degree of confidence from observations made pretty equally over both hemispheres.

2950. If we should ever attain a good knowledge of the annual variation for several stations in different parts of both hemispheres, it would help to give data by which the depth at which the magnetic power is virtually situated might be estimated; for, as this power is expected to undergo undulations over very large portions of the earth's surface by the annual changes of temperature (2884.), so they would differ in character and extent according as the origin of the lines should prove to be more or less deeply situated.

2951. With regard to the many variations of magnetic force, not periodic or not so in relation to the sun, which yet produce the irregular and overruling changes already referred to (2945.), dependent, as I suppose, on local variations of the atmosphere, I may be allowed to notice briefly such points as have occurred to my mind.

2952. The *varying pressure* of the atmosphere, over a given part of the earth's surface, ought to cause a variation in the magnetic condition of that part of the earth. It is represented to us by a difference of three inches of mercury, or one-tenth of the weight of the atmosphere. Now the oxygen in a given space is paramagnetic in proportion to its quantity (2780.), and therefore it does not seem possible that that quantity over a given space of the earth's surface, whether it be recognised by volume as above, or by weight as in a given volume at the earth's surface, should be varied to the extent of one-tenth of the whole sum without producing a corresponding alteration in the distribution of the magnetic force; the lines being drawn together and the force made more intense by an increase of the quantity or of the barometric pressure, and the reverse effects produced at the occurrence of diminished pressure.

2953. At any spot which is towards the confines of that space where the air is increasing or diminishing in pressure, there will probably occur variations in the directions of the lines of force, and these will be more marked at such places as happen to be between two others, in one of which atmosphere is accumulating, whilst from the other it is retreating. Whether these changes (which I think must occur) produce by vicinity effects large enough to become sensible in our magnetic instruments, is a question to be resolved hereafter. To suggest the cause is useful, because to know of the existence, nature, and action of a cause, is important to the arrangement of the best means of observing and evolving its effects.

2954. *Winds and large currents of air above* may often be accompanied by magnetic changes if they endure for a time only. A constant stream like the trade-wind, may have a constant effect; but if, when the arrangement of the lines of magnetic force through the atmosphere is in a given state consequent upon the condition of the atmosphere at that time, a wind arises which mixes regions of cold and warm air together, or makes the air more dense in one region than another, or proceeding from one to another, balances regions which before were in different conditions, then every such change will be accompanied by a corresponding change in the disposition of the magnetic force, to which we may perhaps hereafter be able to refer by means of our instruments. Even tides in the air ought to produce an effect, though it may be far too small to be rendered sensible.

2955. The precipitation of *rain or snow* is a theoretical reason for the change of magnetic relations in the space where it takes place; because it alters the temperature where such precipitation occurs, and relieves it from a quantity of diluting diamagnetic or neutral matter. A *chilling hail-storm might* affect the needle in a summer's day. *Clouds* may have a sensible influence in several ways; acting at one time by their difference from neighbouring regions of clear air, and at other times by absorbing the sun's rays, and causing the evolution of sensible heat at different altitudes in the atmosphere at different places, or preventing its evolution more or less at the surface of the earth. Those masses of warmer or colder air of which meteorologists speak, which being transparent are not sensible to the eye, will produce their proportionate effect. And hypothetically speaking, it is not absolutely impossible that the hot and partially deoxygenated air of a large town like London, may affect instruments in its vicinity; and if so, it will affect them differently at different times, according to the direction of the wind.

2956. If one imagines on the surface of the earth a spot which shall represent the resultant there of the atmospheric actions above, and can conceive its course as it wanders to and fro, under the influence of the various causes of action which have been in part referred to, whilst it still travels onwards with the sun, one may have an idea of the manner in which it may affect the various observatories scattered over the earth. I believe that its course, as regards the east and west direction of its wanderings, is partly told in the photographic registerings of Greenwich and Toronto, being there mingled in effect with other causes of variation. This spot may be concentrated or diffuse; it may pass away and reappear elsewhere; there may even be two or more at once sufficiently strong to cause vibrations of the needle between them.

2957. The aurora borealis or australis can hardly be independent of the magnetic constitution of the atmosphere, occurring as it does within its regions, and perhaps in the space above. The place of the aurora is generally in those latitudes the air of which has a distinct magnetic relation, by difference of temperature and quantity, to that at the equator, and the magnetic character both of the aurora and of the medium in which it occurs ties them together; therefore, to be aware of and to understand in some degree the latter, will probably direct us to a better comprehension of the former. The aurora is already connected with magnetic disturbances and storms; it may in time connect them with changes in the atmosphere in a manner not at present anticipated, and as the suggestion is founded upon principle it seems deserving of consideration.

2958. Can the magnetic storms of HUMBOLDT be due to atmospheric changes? This is a question on which I would offer the following observations. Supposing a magnetic rest in the atmosphere, and that all local or irregular variations remained unchanged for the time, then if a change happened in one place it would be felt instantly everywhere else over the whole earth, and in proportion to the distance from the place of change. It would be felt instantly, because the impulse would not be conveyed chiefly or importantly through the matter of the earth or air, but through the space above, for the lines there are affected by changes in that part of them which passes through the atmosphere, and, as I conceive, would affect the other lines in space round our globe, which would in turn affect those parts of their lines, which, passing downwards to the earth, govern the needles below. In space, I conceive that the magnetic lines of force, not being dependent on or associated with matter (2787. 2917.), would have their changes transmitted with the velocity of light, or even with that higher velocity or instantaneity which we suppose to belong to the lines of gravitating force, and if so, then a magnetic disturbance at one place would be felt instantaneously over the whole globe.

2959. But the difficulty is to conceive an atmospheric change sufficiently extensive and sudden to make itself perceived everywhere at the same time amongst the comparatively local variations that are continually occurring. Still, if there were a lull in these disturbances by the opposition of contrary actions or otherwise for the same moment of time at two or more places, those places might show a simultaneous effect of disturbance, and that even when the cause might be very little or not at all sensible in the place where it occurred. A simultaneous change over an area of 600 or 800 miles in diameter, might produce less alteration in the middle of that area than at the extremities of radii of 1000 miles.

2960. It becomes a fair question of principle to inquire how far masses of the air may be *moved* by the power of the magnetic force which pervades them. When two bulbs of oxygen in different states of density are subjected to a powerful magnet with an intense field of force, the mechanical displacement of one by the other is most striking. Whether in nature the enormous volumes of air concerned, and the difference in intensity of the earth's magnetic force at the different latitudes where these may be supposed to be located, combined with the difference of temperature, are sufficient to compensate for the small portions of oxygen in the air and the smaller variations in density, is a matter that cannot at present be determined. The differential result of motion, as has been shown, is very great where the direct result, as of compression, is not merely very small but nothing (2774. 2750.), and the atmosphere is a region where the differential action of enormous masses is concerned.

2961. Now in the matter of difference of intensity, GAY-LUSSAC and BIOT conclude from their observations*, that the magnetic force is the same at a height of four miles as at the surface of the earth. M. KUPFFER, however, draws from GAY-LUSSAC'S results the conclusion, that there was a little diminution, and Professor Forbes, from his experiments made in different parts of Europe*, concludes that there is a decrease of the force upwards. Such decrease may be a real consequence due to the difference of distance from the source of the terrestrial magnetic force; or, as is more likely, it may be due to the different proportions of oxygen there and at the surface of the earth. According to Gay-Lussac's account of the air brought from above, it was as 0·5 to 1·0, compared with the density below. Hence the paramagnetic power, added to space in the place above, from whence the air was taken, would not be more than one-half of that added by the presence of the denser atmosphere below. This I think ought to make a change in the distribution of the magnetic force; it would almost certainly do so at the equator, where the lines of force are parallel to the general direction of the atmosphere (2881.); and I think it would do so, as to the horizontal component, in the latitude where Gay-Lussac and Biot made their aërial voyages. It is also just possible that the observers may have been in such relation to the heated or cooled air about them as to have had the difference observed produced, or rather affected, by some of the circumstances just described (2951.).

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* Annales de Chimie, An. xiii. vol. lii. p. 86.

2962. Whether the result obtained by Gay-Lussac and Biot indicate a change of power due to distance or not, this we know, that there *are* great changes from the magnetic equator toward the north and south; and that, as Humboldt and Bessel say, it is doubled in proceeding from the equator to the western limits of Baffin's Bay. And when so little as one-third of a cubic inch of oxygen can exert a force equal to the tenth of a grain, subject to the action of our powerful magnet, we may well conceive that the enormous sum of oxygen present, in only a few miles of heated or cooled atmosphere, can compensate for the great difference of magnetic force, and so, by a change of place, cause currents or winds having their origin in magnetic power. In such a case we should have a relation of magnets to storms; and the magnetic force of the earth would have to do with the mechanical adjustments and variations of the atmosphere, sometimes causing currents which without it might not exist, and at other times opposing those which might else arise, according as the great differential relations by which it would act (2757.) should combine with or oppose the other natural causes of motion in the air. Such movements would react upon the magnetic forces, so that these would readjust themselves, and so there would be magnetic storms, both material and potential, in the atmosphere, as there are supposed to be of the latter kind in the earth.

2963. In bringing this communication to a close, I have to express my obligations to two kind and able friends, Colonel Sabine and Professor Christie, for the interest they have taken in the subject, and on the part of the former for the extreme facilities afforded me in the use of observations and the data derived from them; but in doing so I must be careful not to convey any idea that they are at all responsible for the peculiar views I have ventured to put forth. I may well acknowledge that much which I have written has been upon very insufficient consideration; but hoping that there might be some foundation of truth in the account of the physical cause of the variations which I have ventured to suggest, I have not hesitated to put it forth, trusting that it might be for the advantage of science. The magnetic properties and relations of oxygen are perfectly clear and distinct, and are established by experiment (2774. 2780.); and it is no assumption to carry these properties into the atmosphere, because the atmosphere, as a mere mixture of oxygen and nitrogen, is shown to possess them also (2862.)*. It varies in its magnetic powers, by causes which act upon it under natural circumstances, and make it able to produce some such effects as those I have endeavoured generally to describe.

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* Edin. Phil. Trans., 1836, vol. xiv. p. 25.

2964. If it be a cause, in part only, of the observed magnetic variations, it is most important to identify and distinguish such a source of action, even though imperfectly, for the attention is then truly and intelligently directed in respect of the action and the phenomena it can produce. The assigned cause has the advantage of occurring periodically and for the same periods, as a large class of the effects supposed to be produced by it; and if the agreement should appear at first only general, still that agreement will greatly strengthen its claim to our attention. It has the advantage of offering explanations and even suggestions of many other magnetic events besides those which are periodical, and it presents itself at a time when we have no clear knowledge of any other physical cause for the variations, but are constrained vaguely to refer them to imaginary currents of electricity in the air or space above, or in the earth beneath.

2965. The causes, both of the original power and of its secular variations, are unknown to us. But if, accepting the earth as a magnet, we should be able to distinguish largely between internal and external action, and so separate a great class of phenomena from the rest, we should be enabled to define more exactly that which we require to know in both directions, should be competent to state distinctly the problems which need solution, and be far better able to appreciate any new hints from nature respecting the *source* of the power and the effects that it presents to us.

2966. The magnetic constitution of oxygen seems to me wonderful. It is in the air what iron is in the earth. The almost entire disappearance of this property also, when it enters into combination, is most impressive, as in the oxynitrogens and oxycarbons, and even with iron, which it reduces into a condition far below either the metal or the oxygen, weight for weight. Again, its striking contrast with the nitrogen, which dilutes it, impresses the mind, and by the difference recalls that which also exists between them in relation to static electricity (1464.) and the lightning flash. Chlorine, bromine, cyanogen and its congeners, chemically speaking, have no magnetic relation to oxygen. In nature it stands in this respect, as in all its chemical actions, alone.

2967. There is much to do with oxygen relative to atmospheric magnetism. Its proportion of paramagnetic force at different temperatures and different degrees of rarefaction, will require to be accurately ascertained, and this I hope to effect by a torsion balance, in course of construction (2783.). Indeed, I hope that this great subject may be largely touched and tried by experiment as well as by observation, and therefore gladly make it part of these experimental researches.

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* Philosophical Magazine, 1847, vol. xxxi. pp. 409, 406.

2968. One can scarcely think upon the subject of atmospheric magnetism without having another great question suggested to the mind (2442.), What is the final purpose in nature of this magnetic condition of the atmosphere, and its liability to annual and diurnal variations, and its entire loss by entering into combination either in combustion or respiration? No doubt there is one or more, for nothing is superfluous there. We find no remainders or surplusage of action in physical forces. The smallest provision is as essential as the greatest. None are deficient, none can be spared.

Royal Institution,
September 14, 1850.

APPENDIX.

Received November 12, 1850.

The following Tables of data obtained at Toronto, St. Petersburgh, Washington, Lake Athabasca and Fort Simpson, supplied to me by the kindness of Colonel Sabine, have not yet been published. The data for Hobarton and Greenwich are in the volumes of observations for those stations.

Toronto.—Longitude 77° 5′ West. Latitude 43° 40′ North. Approximate declination 1° 25′ West. Mean inclination 75° 15′ North.

Diurnal variation of the Declination in the several months, from July 1842 to June 1848 inclusive.

Increasing numbers denote a movement of the south or upper end of the magnet towards the West.

Toronto mean time.	0^{h}. Noon.	1^{h}.	2^{h}.	3^{h}.	4^{h}.	5^{h}.	6^{h}.	7^{h}.	8^{h}.	9^{h}.	10^{h}.	11^{h}.	12^{h}. Midn.	13^{h}.	14^{h}.	15^{h}.	16^{h}.	17^{h}.	18^{h}.	19^{h}.	20^{h}.	21^{h}.	22^{h}.	23^{h}.	Daily means.
January	0′·87	0′·00	0′·00	0′·53	1′·44	2′·28	2′·89	3′·47	4′·43	4′·53	4′·39	4′·06	3′·66	3′·42	3′·63	3′·87	4′·46	3′·84	3′·88	4′·44	5′·48	5′·80	4′·79	3′·03	3·30
February......	0·78	0·00	0·06	0·94	1·58	1·91	2·73	3·13	4·02	4·44	4·69	4·45	4·31	3·81	3·54	4·07	3·97	4·86	4·95	5·20	5·97	5·70	4·64	2·53	3·43
March.........	1·44	0·01	0·00	0·59	1·74	2·90	3·82	4·77	5·63	6·60	6·47	6·86	6·04	6·42	6·55	6·34	6·69	6·59	7·10	8·30	9·38	9·40	7·15	4·22	5·21
April	1·25	0·00	0·16	1·02	2·76	4·12	5·14	6·31	7·05	7·14	7·60	7·66	7·39	7·32	7·65	7·82	8·08	8·33	9·46	10·09	10·20	9·10	6·87	3·74	6·09
May............	1·16	0·00	0·29	1·56	3·24	5·11	6·08	6·27	6·18	6·75	7·36	7·49	7·40	7·26	6·72	7·10	7·80	9·70	11·02	12·16	12·03	10·28	6·90	3·52	6·39
June	1·37	0·00	0·02	0·94	2·53	4·35	5·45	6·11	6·10	6·66	6·66	6·87	6·77	6·50	6·37	6·36	7·29	9·03	11·34	12·34	12·09	10·54	7·67	4·04	6·12
July............	1·53	0·09	0·00	0·84	2·18	3·98	5·20	5·77	6·31	6·34	7·31	7·38	7·67	7·06	6·42	6·37	6·86	8·53	10·54	12·01	12·22	10·69	7·65	4·27	6·13
August	1·11	0·00	0 73	2·61	4·52	6·12	7·60	7·52	8·05	8·97	8·51	8·40	8·14	7·69	7·65	7·83	8·24	9·50	12·09	13·89	13·79	11·51	7·31	3·73	7·31
September ...	0·03	0·00	0·76	2·92	4·62	6·04	6·78	6·83	7·62	7·84	7·83	7·08	7·50	7·66	7·53	7·77	8·45	8·38	9·79	11·16	10·24	8·60	5·34	2·25	6·37
October	0·48	0·00	0·31	1·38	2·38	3·06	3·84	4·33	4·92	5·76	5·68	5·48	5·00	5·21	4·89	5·16	5·82	5·74	5·50	6·39	7·32	7·02	5·17	2·63	3·89
November ...	0·75	0·00	0·34	1·37	2·21	2·91	3·96	4·89	5·16	5·70	5·54	5·26	4·51	3·79	3·80	4·51	4·44	4·99	4·95	5·70	6·31	6·08	4·57	2·35	3·92
December ...	1·20	0·18	0·00	0·61	1·67	2·56	3·30	3·89	4·39	4·62	4·95	4·48	4·09	3·49	3·04	3·56	3·92	4·02	3·81	4·18	4·50	5·22	4·67	2·83	3·30

Toronto.—Mean Diurnal variation of the Inclination in the several months, from July 1842 to June 1848.

Increasing numbers denote increasing inclination.

Toronto mean time.	0^{h}.	1^{h}.	2^{h}.	3^{h}.	4^{h}.	5^{h}.	6^{h}.	7^{h}.	8^{h}.	9^{h}.	10^{h}.	11^{h}.	12^{h}.	13^{h}.	14^{h}.	15^{h}.	16^{h}.	17^{h}.	18^{h}.	19^{h}.	20^{h}.	21^{h}.	22^{h}.	23^{h}.	Daily means.
January	1′·02	0′·77	0′·53	0′·22	0′·00	0′·09	0′·16	0′·21	0′·25	0′·33	0′·34	0′·38	0′·47	0′·54	0′·58	0′·45	0′·33	0′·28	0′·22	0′·21	0′·36	0′·54	1′·04	1′·06	0·43
February......	0·86	0·61	0·36	0·12	0·01	0·00	0·09	0·12	0·19	0·26	0·27	0·31	0·37	0·45	0·49	0·44	0·41	0·30	0·27	0·44	0·69	0·70	0·79	0·86	0 39
March.........	1·02	0·77	0·47	0·14	0·00	0·00	0·12	0·22	0·24	0·35	0·40	0·44	0·45	0·53	0·50	0·50	0·46	0·46	0·47	0·62	0·81	0·95	1·00	1·05	0·50
April	0·99	0·77	0·54	0·17	0·05	0·00	0·14	0·35	0·49	0·53	0·49	0·61	0·56	0·59	0·64	0·61	0·60	0·66	0·74	0·80	0·90	1·03	1·16	1·16	0·61
May............	0·83	0·52	0·22	0·06	0·00	0·11	0·27	0·33	0·47	0·62	0·64	0·66	0·76	0·86	0·87	0·89	0·92	1·04	1·00	1·01	1·11	1·29	1·30	1·12	0·70
June	0·89	0·60	0·26	0·05	0·00	0·00	0·16	0·34	0·53	0·68	0·73	0·83	0·84	0·90	0·91	0·98	1·03	1·05	1·08	1·12	1·17	1·27	1·37	1·19	0·75
July............	0·67	0·55	0·17	0·07	0·00	0·06	0·17	0·24	0·39	0·40	0·51	0·56	0·62	0·56	0·66	0·78	0·83	0·87	0·81	0·80	0·88	1·03	1·14	0·93	0·57
August	0·85	0·51	0·21	0·00	0·02	0·04	0·25	0·40	0·42	0·44	0·48	0·55	0·53	0·64	0·65	0·73	0·74	0·84	0·89	1·00	1·09	1·25	1·26	1·13	0·62
September ...	1·35	0·82	0·35	0·10	0·00	0·10	0·29	0·49	0·53	0·55	0·57	0·63	0·68	0·70	0·70	0·75	0·57	0·65	0·68	0·95	1·28	1·64	1·85	1·71	0·75
October	0·93	0·67	0·39	0·14	0·00	0·06	0·21	0·30	0·37	0·39	0·40	0·49	0·62	0·45	0·40	0·33	0·22	0·22	0·32	0·55	0·85	1·04	1·15	1·11	0·48
November ...	0·94	0·75	0·45	0·22	0·11	0·18	0·12	0·18	0 20	0·20	0·23	0·33	0·33	0·31	0·21	0·22	0·12	0·07	0·00	0 08	0·42	0·14	0·89	1·00	0·32
December ...	0·91	0·88	0·51	0·27	0·05	0·01	0·02	0·16	0·21	0·27	0·33	0·30	0·38	0·34	0·28	0·22	0·14	0·08	0·09	0·00	0·17	0·34	0·66	0·81	0·31
Hourly means	0·94	0·69	0·37	0·13	0·02	0·05	0·17	0·28	0·36	0·42	0·45	0·51	0·55	0·57	0·57	0·58	0·53	0·54	0·55	0·63	0·81	0·93	1·13	1·10	0·54

Toronto.—Mean Diurnal variation of the Total Force in the several months, from July 1842 to June 1848.

Increasing numbers denote increasing Force. Mean Total Force at Toronto 13·9.

The figures express the changes in parts of the whole Force.

Toronto mean time.	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	Daily means.
	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
January	005	011	017	023	022	024	023	023	023	020	019	015	010	009	004	003	004	005	008	009	010	003	000	000	012
February......	006	012	019	022	024	026	026	027	025	023	019	017	009	005	003	004	003	006	009	010	016	004	000	001	013
March.........	004	011	019	026	029	031	031	031	028	025	020	014	005	002	002	002	003	003	010	013	013	007	002	000	014
April	012	020	031	039	045	045	044	039	034	027	020	012	008	007	003	000	009	011	013	012	012	009	006	006	019
May............	004	013	015	031	038	042	038	035	029	025	017	011	004	002	002	003	008	010	015	013	009	003	000	000	015
June	003	008	017	025	029	031	030	028	022	018	014	011	006	002	002	001	006	011	014	014	010	005	002	000	013
July...........	015	019	030	038	044	047	043	039	031	026	021	015	007	004	000	002	005	011	016	017	015	014	010	002	020
August	027	034	044	042	057	057	051	046	041	032	023	010	006	001	003	000	006	018	026	026	024	019	019	021	026
September ...	029	043	053	060	060	056	052	050	044	038	034	029	019	007	000	001	004	009	018	022	028	015	016	021	030
October	013	021	027	032	032	033	033	034	031	026	023	018	007	003	005	002	000	005	011	014	018	011	008	006	017
November ...	007	014	022	026	028	025	025	028	024	018	015	011	007	004	001	003	000	003	007	009	008	002	001	003	011
December ...	004	010	019	020	023	021	021	021	019	018	017	012	010	008	006	007	003	003	007	006	006	006	001	000	011
Hourly means	011	018	026	032	036	037	035	033	029	025	020	015	008	005	003	002	004	008	013	014	014	008	005	006	017

Toronto.—Mean Temperature of the Air in the several months, from July 1842 to June 1848, in degrees of FAHRENHEIT's scale.

Toronto mean time.	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	Daily means.
January	27°·8	28°·3	28°·6	28°·5	28°·0	27°·1	26°·3	25°·8	25°·5	25°·3	26°·3	24°·6	25°·6	23°·5	23°·4	21°·6	23°·2	23°·0	23°·7	23°·6	23°·9	24°·8	26°·0	27°·1	25°·48
February......	27·4	28·2	28·5	28·5	28·0	26·9	25·6	24·6	23·8	23·2	22·7	22·2	22·0	21·7	21·3	20·9	20·5	20·2	20·0	19·9	20·9	22·9	24·9	26·3	23·80
March.........	33·8	34·4	35·0	34·9	34·3	33·6	31·9	30·5	29·5	28·6	28·0	27·3	27·3	26·8	26·3	26·2	25·8	25·5	25·0	25·9	27·8	29·9	31·6	32·8	29·71
April	47·6	48·5	49·0	49·0	48·6	47·9	46·1	43·5	41·8	40·7	39·8	39·3	39·1	38·6	37·9	37·3	37·0	36·6	36·8	39·2	41·5	43·6	45·2	46·6	42·55
May............	59·0	59·9	60·2	60·3	60·3	59·9	58·1	55·2	52·6	50·7	49·7	48·8	48·0	46·9	46·3	45·6	45·1	45·2	47·6	50·6	53·0	55·2	56·8	58·0	53·04
June	66·7	67·5	67·9	68·3	68·5	68·1	66·6	63·9	60·6	58·4	57·0	56·1	55·7	54·8	54·1	53·3	52·7	52·9	55·6	58·5	60·8	62·7	64·4	65·6	60·86
July	72·9	73·7	74·5	74·8	74·7	74·3	72·7	69·2	65·1	62·9	61·8	60·7	59·8	58·9	58·3	57·6	56·9	56·9	59·8	63·4	66·0	68·2	70·1	71·5	66·02
August	73·0	73·9	74·5	74·8	74·6	74·1	72·5	68·4	65·3	63·6	62·4	61·6	60·7	60·0	59·4	58·7	58·3	58·1	59·6	63·2	66·3	68·7	70·6	72·1	66·43
September ...	63·9	64·5	64·9	64·9	64·7	63·7	61·1	58·3	57·1	56·0	54·9	54·2	53·8	53·3	52·7	52·2	51·6	51·1	51·7	54·2	57·0	59·5	61·5	62·9	57·90
October	49·7	50·3	50·5	50·3	49·6	47·8	45·8	44·7	43·9	43·1	42·3	41·6	41·0	40·4	40·1	39·9	39·5	39·4	39·6	40·4	42·8	45·6	47·5	48·9	44·35
November ...	39·5	40·0	40·1	39·9	39·0	37·7	36·9	36·3	35·9	35·7	35·3	34·9	34·3	34·0	33·7	33·4	33·2	33·3	33·6	33·6	34·6	36·2	37·7	38·8	36·15
December ...	29·9	30·4	30·7	30·5	29·8	28·9	28·2	27·9	27·5	27·3	27·0	26·9	26·6	26·0	25·7	25·5	25·5	25·5	25·1	25·0	25·4	26·6	27·9	29·1	27·44
Hourly means	49·27	49·97	50·37	50·39	50·01	49·17	47·65	45·69	44·05	42·96	42·27	41·52	41·16	40·41	39·93	39·35	39·11	38·97	39·84	41·46	43·33	45·32	47·02	48·31	44·48

St. Petersburgh.—Longitude 38° 18′ East. Latitude 59° 57′ North. Mean declination 6° 10′ West.

Mean Diurnal variation of the Declination in the several months, from 1841 to 1845 inclusive.

Increasing numbers denote a movement of the south or upper end of the magnet towards the West.

Mean time ...	Noon. h m 0 21½	h m 1 21½	h m 2 21½	h m 3 21½	h m 4 21½	h m 5 21½	h m 6 21½	h m 7 21½	h m 8 21½	h m 9 21½	h m 10 21½	h m 11 21½	Midn. h m 12 21½	h m 13 21½	h m 14 21½	h m 15 21½	h m 16 21½	h m 17 21½	h m 18 21½	h m 19 21½	h m 20 21½	h m 21 21½	h m 22 21½	h m 23 21½	Means.
January	0′·27	0′·00	0′·36	1′·24	1′·59	1′·99	2′·39	3′·28	4′·03	4′·65	4′·56	4′·65	4′·43	3′·72	3′·77	3′·10	2′·57	2′·22	2′·35	2′·17	2′·08	1′·86	1′·42	1′·02	2·49
February......	0·84	0·00	0·09	0·57	1·55	2·84	3·54	3·63	4·03	5·18	5·67	5·49	5·27	4·52	4·34	4·65	4·34	3·90	4·03	3·77	3·50	3·23	2·61	1·46	3·29
March.........	0·89	0·00	0·04	1·15	2·88	4·16	5·36	6·29	6·73	6·78	7·40	7·84	6·69	6·51	5·76	6·11	6·38	6·16	6·65	6·56	6·73	6·38	4·96	2·79	5·05
April	1·59	0·00	0·36	2·17	4·03	5·54	7·04	7·93	8·33	8·02	9·30	9·17	8·68	8·46	8·73	8·59	9·17	9·30	9·48	10·01	10·68	9·75	7·58	4·61	7·01
May...........	1·02	0·00	0·62	2·13	3·68	5·49	6·96	7·44	7·18	6·82	7·44	8·24	8·55	8·73	8·82	9·66	10·23	10·72	11·12	11·39	11·12	9·92	7·49	3·54	7·01
June	1·77	0·00	0·00	1·37	2·92	4·52	5·76	6·25	6·25	6·56	7·13	7·13	7·49	8·28	8·68	9·70	10·23	10·94	11·30	11·39	11·52	10·10	7·35	4·12	6·70
July...........	1·46	0·04	0·00	1·11	2·39	3·94	4·96	5·27	5·98	5·98	6·78	7·49	7·66	7·71	8·42	8·55	9·30	9·52	9·83	9·75	9·04	8·46	6·96	3·90	6·02
August	0·27	0·00	0·40	2·44	4·16	5·94	7·04	6·73	7·49	7·27	7·35	7·27	8·02	8·11	8·06	8·55	9·30	9·88	10·19	10·19	9·44	8·42	5·67	3·15	6·47
September ...	0·57	0·00	0·84	2·57	4·30	6·33	6·78	7·49	7·97	8·06	8·33	7·49	7·04	7·31	7·40	6·78	7·04	6·91	7·27	7·31	7·13	6·25	4·12	1·95	5·72
October	0·31	0·00	0·48	1·77	3·59	4·08	4·87	5·76	6·02	6·56	6·91	6·20	5·71	5·18	4·78	4·39	4·16	3·99	4·21	4·83	5·09	4·65	3·32	1·59	4·10
November ...	0·09	0·00	0·36	1·55	1·90	2·71	2·79	3·15	3·81	4·39	4·47	4·34	3·68	3·06	2·75	2·35	2·22	1·82	1·82	1·90	1·77	1·77	0·93	0·57	2·26
December ...	0·53	0·00	0·36	1·24	1·82	2·39	2·79	2·97	4·03	4·56	4·56	4·52	3·68	3·10	2·88	2·53	2·04	1·82	1·77	1·77	1·82	1·68	1·28	0·93	2·29
Hourly means	0·80	0·00	0·33	1·61	2·90	4·16	5·02	5·52	5·99	6·24	6·66	6·65	6·41	6·22	6·20	6·25	6·42	6·43	6·67	6·75	6·66	6·04	4·47	2·47	4·87

St. Petersburgh.—Mean Temperature of the Air in the several months, from 1841 to 1845 inclusive. FAHRENHEIT's scale.

Mean time ...	Noon. h m 0 21½	h m 1 21½	h m 2 21½	h m 3 21½	h m 4 21½	h m 5 21½	h m 6 21½	h m 7 21½	h m 8 21½	h m 9 21½	h m 10 21½	h m 11 21½	Midn. h m 12 21½	h m 13 21½	h m 14 21½	h m 15 21½	h m 16 21½	h m 17 21½	h m 18 21½	h m 19 21½	h m 20 21½	h m 21 21½	h m 22 21½	h m 23 21½
January	20°·28	20°·71	20°·67	20°·41	19°·82	19°·89	19°·73	19°·71	19°·74	19°·76	19°·67	19°·49	19°·38	19°·33	19°·29	19°·19	19°·04	18°·90	18°·79	18°·79	18°·74	18°·81	19°·24	19°·98
February......	18·34	18·58	18·70	18·65	18·27	17·35	16·88	16·52	16·32	16·09	15·95	15·67	15·55	15·48	15·39	15·19	14·97	14·88	14·76	14·65	15·19	15·66	16·61	17·35
March.........	25·61	26·30	26·97	27·01	27·01	26·13	24·74	23·88	23·20	22·44	21·94	21·31	20·70	20·07	19·62	19·26	18·84	18·54	18·34	18·74	19·87	21·38	22·95	24·53
April	37·85	38·07	38·58	38·81	39·53	38·63	36·54	34·62	33·35	32·38	31·42	30·72	30·07	29·55	29·08	28·61	28·36	28·42	29·21	30·63	32·16	33·75	35·39	36·79
May	53·46	53·80	54·31	54·72	55·10	54·29	52·23	49·84	47·91	46·19	45·38	43·90	43·16	42·37	41·83	41·47	41·56	42·73	44·19	46·06	47·88	49·57	51·17	52·65
June	63·03	63·48	63·83	64·36	64·97	64·07	61·90	59·97	58·19	56·48	55·04	54·07	53·26	52·58	52·00	51·50	52·27	53·33	54·95	56·57	58·21	59·72	59·02	62·15
July...........	66·44	66·93	67·21	67·46	67·93	67·26	65·28	63·61	62·01	60·57	59·56	58·86	58·05	57·33	56·86	56·48	56·68	57·53	58·86	60·59	62·06	63·43	64·76	65·90
August	67·10	68·00	68·56	68·69	69·23	68·56	65·73	63·70	62·26	60·89	60·08	59·22	58·14	57·60	57·20	56·57	56·14	56·73	57·65	59·45	61·29	63·12	64·71	66·06
September ...	54·50	55·66	55·91	55·78	55·83	54·56	52·62	51·16	50·15	49·43	48·89	48·31	47·75	47·25	46·85	46·44	46·26	46·06	46·17	47·21	48·76	50·56	52·20	53·37
October	41·92	44·80	42·76	41·98	41·78	40·92	40·30	39·89	39·56	39·31	38·86	38·52	38·32	38·14	38·00	37·85	37·73	37·67	37·53	37·71	38·28	39·11	40·12	41·04
November ...	29·73	30·22	30·88	29·75	29·26	28·96	28·83	28·67	28·58	28·41	28·52	28·49	28·47	28·45	28·42	28·27	28·13	28·04	28·00	27·95	28·07	28·42	28·83	29·37
December ...	26·04	26·45	26·40	26·27	26·13	25·91	25·70	26·02	25·52	25·48	25·48	25·32	25·21	25·12	24·96	24·85	24·85	24·92	25·03	25·03	25·14	25·25	25·39	25·79

Washington, U.S—Longitude 77° 2′ West. Latitude 38° 54′ North. Mean declination 1° 25′ West. Mean dip 71° 20′ North.

Mean Diurnal variation of the Declination in minutes, and temperature in Fahrenheit's scale, of the months of the years 1840, 1841, 1842, which are specified.

Increasing numbers denote a movement of the south or upper end towards the East.

Mean time	Noon. h m 0 12	h m 2 12	h m 4 12	h m 6 12	h m 8 12	h m 10 12	h m 12 12	h m 14 12	h m 16 12	h m 18 12	h m 20 12	h m 22 12	Mean.
January 1841–42	4′·10	5′·20	3′·96	2′·52	0′·87	0′·68	1′·01	1′·62	1′·66	1′·71	0′·91	0′·29	2′·04
February 1841–42	3·55	5·28	4·22	2·89	1·59	0·94	0·84	1·26	0·81	0·82	0·60	0·35	1·76
March 1841–42 ...	6·34	7·51	6·26	4·25	2·88	2·31	2·50	3·00	1·71	1·13	0·00	1·76	3·30
April 1841–42 ...	6·56	8·33	6·42	4·41	3·22	1·97	2·24	1·35	0·73	0·46	0·00	2·18	3·15
May 1841–42......	7·72	8·57	6·36	4·45	3·82	3·47	3·25	3·05	2·63	0·33	0·00	4·25	3·99
June 1841–42......	8·55	9·47	8·00	5·33	4·91	4·24	4·05	4·32	3·44	0·63	0·00	4·53	4·79
July 1840–41......	8·42	9·87	8·07	5·75	4·57	3·52	3·60	3·40	2·99	0·98	0·00	3·62	4·56
August 1840–41...	10·94	10·81	7·95	6·00	4·03	3·55	4·48	4·64	4·04	1·35	0·00	5·89	5·30
Sept. 1840–41......	8·76	8·44	5·43	4·45	2·62	3·31	2·83	2·86	2·44	0·87	0·00	4·22	3·85
October 1840–41	5·65	5·83	4·35	2·47	1·41	0·58	1·41	1·80	1·51	1·35	0·00	1·75	2·34
Nov. 1840–41......	4·69	4·79	3·33	1·60	0·51	0·74	1·14	1·41	0·82	0·71	0·00	1·83	1·79
Dec. 1840–41......	3·93	4·90	3·39	1·92	0·10	0·36	0·62	1·53	0·93	2·00	1·02	0·87	1·79

Temperature.

Mean time	Noon. h m 0 12	h m 2 12	h m 4 12	h m 6 12	h m 8 12	h m 10 12	h m 12 12	h m 14 12	h m 16 12	h m 18 12	h m 20 12	h m 22 12
January 1841–42	38°·28	40°·83	40°·18	36°·68	35°·47	34°·24	32°·37	32°·10	31°·71	30°·53	31°·63	36°·96
February 1841–42	40·03	42·51	42·28	38·22	35·38	33·86	32·58	31·22	30·51	30·18	31·44	36·72
March 1841–42 ...	51·39	53·61	53·28	49·96	46·20	44·37	42·48	41·26	40·06	39·87	42·28	48·06
April 1841–42 ...	57·68	59·81	60·20	57·21	52·18	49·12	47·91	46·91	46·12	46·49	49·93	54·02
May 1841–42......	66·37	68·48	68·69	65·93	59·83	56·70	55·19	53·34	52·42	55·50	59·72	63·23
June 1841–42......	79·32	81·85	82·75	76·89	72·29	68·70	66·83	66·04	65·07	68·26	73·63	77·37
July 1841	81·13	81·53	84·60	81·33	74·93	71·56	68·78	68·09	66·78	70·64	75·19	78·38
August 1840–41...	78·70	80·73	80·09	75·93	71·48	68·00	66·82	65·12	64·17	65·69	65·73	76·09
September 1841...	74·66	76·50	76·30	72·30	68·59	64·90	62·70	61·90	61·00	61·29	65·73	71·02
October 1841......	55·30	57·00	56·20	52·94	48·40	46·60	44·90	43·70	42·30	41·70	45·00	51·61
November 1841 ...	48·00	49·20	48·50	47·30	44·20	43·20	41·80	40·70	39·40	38·80	39·50	44·10
December 1841 ...	39·20	41·30	40·60	37·95	36·26	34·70	33·50	33·16	32·20	31·60	31·69	36·00

Lake Athabasca.—Longitude 111° 18′ West. Latitude 58° 41′ North. Mean declination 28° East.

Diurnal variation of the Declination in the months of October, November and December 1843, and January and February 1844.

Increasing readings denote a movement of the south or upper end of the magnet towards the West.

Mean time	h m 12 55	h m 13 55	h m 14 55	h m 15 55	h m 16 55	h m 17 55	h m 18 55	h m 19 55	h m 20 55	h m 21 55	h m 22 55	5 minutes to noon. h m 23 55	h m 0 55	h m 1 55	h m 2 55	h m 3 55	h m 4 55	h m 5 55	h m 6 55	h m 7 55	h m 8 55	h m 9 55	h m 10 55	5 minutes to midnight. h m 11 55	Mean time.
1843. Oct....	1′·13	7′·49	6′·23	18′·95	21′·32	8′·55	13′·35	9·90	10′·72	7′·03	2′·29	2′·70	0′·00	0′·29	0′·02	0′·98	0′·49	2′·88	1′·88	3′·75	3′·47	3′·30	8′·42	0′·49	13 days obs. in Oct. 1843.
Nov....	3·73	5·17	6·74	9·07	10·35	10·80	9·40	8·80	7·63	6·54	1·10	0·00	1·06	1·57	1·93	2·73	2·94	3·34	4·52	4·97	5·43	7·08	3·04	3·63	25 days obs. in Nov. 1843.
Dec....	3·04	6·16	5·57	5·65	9·23	7·61	9·78	6·73	6·58	5·33	1·94	0·55	0·03	0·00	0·83	2·37	2·63	3·81	4·18	3·57	4·35	7·19	4·05	6·05	25 days obs. in Dec. 1843.
1844. Jan....	5·69	8·48	6·97	12·57	16·29	10·05	9·97	10·02	9·96	7·95	4·99	2·10	0·39	0·00	2·75	1·67	2·47	3·63	4·72	5·15	5·44	3·97	6·71	2·18	25 days obs. in Jan. 1844.
Feb....	4·27	4·93	8·46	10·55	14·80	14·87	14·06	12·10	12·76	8·64	2·82	2·93	1·55	0·00	1·48	3·24	3·76	4·52	4·96	5·48	5·58	4·99	6·98	5·40	25 days obs. in Feb. 1844.

Fort Simpson.—Longitude 121° 30′ West. Latitude 61° 52′ North.

Diurnal variation of the Declination in the months of April and May 1844.

Increasing numbers denote a movement of the south or upper end of the magnet towards the West.

Mean time.	15 minutes past midnight. h m 12 15	h m 13 15	h m 14 15	h m 15 15	h m 16 15	h m 17 15	h m 18 15	h m 19 15	h m 20 15	h m 21 15	h m 22 15	h m 23 15	15 minutes past noon. h m 0 15	h m 1 15	h m 2 15	h m 3 15	h m 4 15	h m 5 15	h m 6 15	h m 7 15	h m 8 15	h m 9 15	h m 10 15	h m 11 15	Mean time.
1844. April	5′·82	6′·03	17′·45	25′·16	22′·90	36′·80	36′·26	37′·60	30′·14	25′·27	18′·77	8′·27	5′·72	2′·16	0′·00	1′·37	1′·23	0′·43	0′·30	4′·04	4′·62	1′·26	2′·86	5′·55	20 days obs. in Apr. 1844.
May	1·56	7·77	11·71	15·63	17·19	23·73	28·22	32·69	29·80	20·29	15·51	9·49	4·74	3·75	0·70	0·75	0·80	0·00	0·19	1·90	6·72	3·51	2·29	1·67	18 days obs. in May 1844.

IV. *Experimental Researches in Electricity.—Twenty-seventh Series. By* MICHAEL FARADAY, *Esq., D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Ord. Boruss. Pour le Mérite, Eq., Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, Munich, Bruxelles, Vienna, Bologna, &c. &c.*

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§ 33. *On Atmospheric Magnetism—continued.*

¶ ii. *Experimental inquiry into the laws of atmospheric magnetic action, and their application to particular cases.*

2969. BELIEVING that experiment may do much for the development of the general principles of atmospheric magnetism, and produce rapidly a body of facts on which philosophers may proceed hereafter to raise a superstructure, I endeavoured to find some means of representing practically the action of the atmosphere, when heated by the sun, upon the terrestrial magnetic curves. The object was to obtain some central arrangement of force which should deflect these curves or lines as they are deflected in a diamagnetic conductor or globe of hot air (2877.), and then apply the results obtained by such an arrangement as a partial test to the various cases supplied by the magnetic observatories scattered over the earth. At first I endeavoured, for the sake of convenience, to attain this desired end by means of a horseshoe magnet, employing the lines which passed from pole to pole to disturb and rearrange the earth's force; but the comparative weakness of the terrestrial force near the magnet, and the great prominence of the poles of the latter, gave rise to many inconveniences, which soon caused me to reject that method and have recourse to a ring-helix and voltaic apparatus. Considering the new use to which this helix is to be applied, the interest of the results, and the instruction that may be drawn from them, I shall be excused for being somewhat elementary in the description of its character and action.

2970. The helix consisted of about 12 feet of covered copper wire formed into a ring having about twenty-five convolutions, and being $1\frac{1}{2}$ inch in external diameter. The continuations of the wire were twisted together so as to neutralize any magnetic effect which they could produce, and were long enough to reach to a voltaic arrangement, and yet allow free motion of the helix. The requisite amount of magnetic power in the helix may be judged of by the following considerations:—Suppose a declination needle freely suspended; and then the *helix* placed at a distance in the prolongation of the needle with its axis in a line with the latter, and with that side towards the needle which will at small distances cause repulsion. The needle will point, in the magnetic meridian, with a certain amount of force; but as the helix is brought near it will point with less force, and within a certain distance will no longer point in the magnetic meridian, but either on one or the other side of it. There is a given distance within which the needle, when in the magnetic meridian, is in a position of unstable equilibrium, but beyond which it has a position of stable equilibrium, the distance varying with the strength of the exciting electric current. The power of the helix should be such, that when end on to the needle the latter has a position of stable equilibrium in the meridian. One pair of plates is quite sufficient to make the helix as magnetic as is needful for distances varying from 4 to 24 inches. When a needle is properly arranged with either a magnet or a helix to the north or south of it as above described, if the magnet or helix be moved west the near end of the needle will move east, and contrariwise.

2971. As is well known, such a helix has a system of magnetic lines, which, passing through its axis, then open out and turning round on the outside re-enters again at the axis, the circles of magnetic force being everywhere perpendicular to the electric current traversing the convolutions of the helix; and now I had, at a moment's notice, a source of lines of magnetic power exactly of the kind required to produce, in association with those of the earth, a disposition of the forces coinciding either with those of paramagnetic or diamagnetic polarization (2865. 2877.).

2972. For let fig. 17 represent a section parallel to the axis of the ring-helix, then the two circles may represent the disposition of the magnetic force in that section, and the arrow-heads may serve to indicate that magnetic direction which belongs to lines of force issuing out of the north end of a magnet. If such a system be suddenly produced in the midst of the earth's lines, it acts upon them according to the position of the helix in relation to the direction of the earth's power. Choosing the two positions in which the axis of the helix is parallel to the natural direction of the power, as shown by a free needle, at the place of observation, then two contrary effects are produced, which, as regards the lines exterior to the helix system, correspond to the polarity of paramagnetic and diamagnetic conductors. If, for instance, the helix is so placed that the polarity of its magnetic lines, exterior to and in the plane of the ring, accords with that of the earth's force, as in fig. 18, then the earth's lines are deflected as represented, and a magnetic needle placed at *a*, which had taken up its position by the earth's influence, will not tend to alter its position as the helix approaches it, though it will be acted on with more power. In other parts of the line, *b a c*, it will alter its position, standing as a tangent to the curvature, and therefore will be deflected sometimes one way and sometimes another, as it is carried along the line (or through the neighbouring lines), in place of remaining parallel to itself, as it would do if the electro-magnetic helix were away.

Fig. 17.

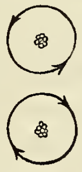
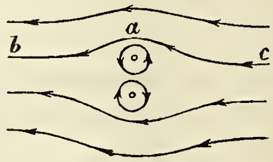


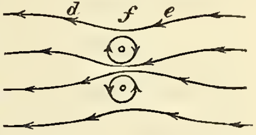
Fig. 18.



2973. On the other hand, if the helix were turned round into the second position

(2972.), then the effect upon the direction of the neighbouring lines of force would be as in fig. 19. Needles placed at *d* and *e* would again be deflected from the natural position given to them by the earth, but they would be deflected in a contrary direction to that which would be taken if they were in corresponding situations under the former arrangement. This figure and state of things represents the paramagnetic disposition of the forces, as the former did the diamagnetic condition.

Fig. 19.



2974. It is not pretended that the whole of these arrangements of forces are like those of the cases of paramagnetic and diamagnetic conductors. Independent systems are here introduced into the midst of the earth's magnetic power, and the central part of each arrangement must therefore be excepted; there are also attractions inwards and repulsions outwards, when the needle is at *a* and *f*, which do not take place in the cases of mere magnetic conduction. But external to these helix systems, the arrangement imposed upon the lines of force from the earth is in accordance with that produced by diamagnetic and paramagnetic conductors, and at distances from 2 inches to 2 or 3 feet; the lines of force thus altered, and those contorted by the sun and atmosphere in the great field of nature, are comparable in their direction, and may be considered as representing each other.

2975. In order to obtain a simple result of the action of such a centre of force on the magnetic lines of the earth, I adjusted a rod in the direction of the dipping-needle, and also a plane at the foot of it parallel to the magnetic equator at London. Then suspending a small magnet, half an inch long, from cocoon-silk, so that when hanging it should be parallel to the magnetic equator, it was adjusted so as to be near to the plane at the foot of the rod representing dip. The ring-helix (2970.) was then associated with the voltaic pair, so that contact could be completed at any moment, and being always retained parallel to itself and to the plane of the magnetic equator, could be brought into the vicinity of the needle on all sides, above or below, and its action upon it observed. As the object was to represent the sun's action, the current was so sent through the helix that its upper face would repel the north end of a magnetic needle; for then a magnet, outside of and in the plane of the ring, would not tend to have its position changed, and the disposition of the forces of the earth under the influence of the helix was as in fig. 18, or like that of a diamagnetic conductor.

2976. In making observations of this kind, and especially if the ring-helix is purposely retained at a considerable distance from the needle, it is better not to connect the helix permanently with the battery and then carry it towards and by the needle, but rather to choose the place where the helix action is to be observed, and when the helix is there to make contact with the battery; the motion and direction of the needle is then easily observed; or if it still, through reason of distance, be feeble, making and breaking contact a few times isochronously with the vibrations of the needle soon raises the effect to any degree required.

2977. There are certain positions in respect of the needle as a centre which must be clearly comprehended. The magnetic axis is a line through the centre of the free regular needle parallel to the direction of the earth's lines of force, whatever that may be, at the place where the experiments may be made. The magnetic equator plane is a plane passing through the centre of the needle perpendicular to the magnetic axis. The plane of the magnetic meridian is that plane which coincides with the magnetic axis, and also with the direction in which the declination needle points. This position always occurs with the magnets that are employed for observation, being a consequence of the method in which they are supported; it would not be taken by a needle placed at right angles on its mechanical axis, the latter being in the magnetic axis.

2978. When the ring-helix, situated as before explained (2975.), was anywhere in the plane of the *magnetic meridian*, it exerted no action on the declination needle tending to change its position. When the helix was anywhere in the plane of the magnetic equator, it exerted no action on the needle to make it change its direction. These are the only places in which the helix does not affect the position of the needle.

2979. These two planes of no variation divide the space around the magnet into four quadrants, and the helix being in any one of these, affects the needle, altering its declination. The deflection of the line of force for two neighbouring quadrants is in the contrary direction, so that as the helix passes from the neutral line into one or the other quadrant, the declination of the needle changes.

2980. If the helix be above or below the magnetic equator and be carried round the magnetic axis travelling along a line of latitude, then the needle makes *one* large oscillation to the right, and another to the left during the circuit. Supposing that the experiment commences with the helix above the equator, and in the plane of the magnetic meridian north of the needle, if it then proceeds by west to south and on by east to its original position the north end of the needle will first go westward; will then stop and return eastward, passing the mean position, and will finally return westward and settle in its first or original direction. All the time the helix is to magnetic east of the needle it will cause the same deflection, and also as long as it is in the west; the deflection will be more or less, but not change in direction as regards the neutral place. The position of the helix north or south of the needle is of no consequence as to the direction of the declination, provided it remain on the same side of the magnetic meridian, though it is to the amount. If the helix be below the magnetic equator the direction of the declination is reversed, but then again it does not change whilst the helix remains east or west of the needle and its plane of mean declination.

2981. If we carry the helix round the needle in a plane perpendicular to the planes of the magnetic equator and meridian, so as to traverse in succession the four quadrants, then the needle makes *two* to and fro vibrations (instead of one) during the circuit. Thus, beginning with the helix in the neutral position over the needle and going round by west and below, and then upwards on the east side to its first position, the north end of the needle will first pass westward, then eastward, then westward, after that eastward, and finally westward to its original or neutral position.

2982. As the helix is carried from the neutral planes (2978.) into any of the quadrants, the power of affecting the declination of the needle is first developed, and then increases every way, from the edges of the quadrant until it attains its maximum force at the middle. Hence the maximum deflection east or west is when the helix is in the middle of each quadrant. Therefore, when the helix is carried from the middle of one quadrant to the middle of the next, only *one motion* in the needle appears; as for instance, an increasing westerly declination, though the direction of the declination in relation to the mean position has been reversed in that time, and there was a moment when the needle had no extra declination, but was *in* that mean position. So also as the helix moves over one quadrant from one neutral plane to another, though the declination of the needle produced by it has not changed in direction, but has been, for instance, all the time west, still the needle will have exhibited two motions, going first west during the increase of the power, and then east whilst it is diminishing; and hence it is that though there are *four* departures of the needle from and return to the neutral or mean position, whilst the helix circumscribes it in an east and west vertical plane (2981.), there are only *two* complete journeys of the needle.

2983. The amount of the deflection diminishes as the distance of the helix from the needle increases; and the contrary.

2984. Two other needles were slung (2975.) very oblique to the magnetic axis, one with its north end upwards and the other with its north end downwards, and these were submitted to the action of the helix as the former had been (2978.). They were affected exactly in the same manner, showing no difference; *i. e.* a given end always moved the same way for the same change in position of the helix. If the helix was very near, then one pole was a little more influenced than the other in certain positions; but its removal further off took away that difference (which is easily accounted for (2970.)) and produced pure results. The place of the helix above or below the prolongation of the line of the needle made *no difference*, provided it was in the same place as regarded the magnetic equator of the earth's lines of force passing through the needle.

2985. For the purpose of establishing the nature of the action which such a helix, always in the given or diamagnetic position (2975.), would exert upon the *inclination*, a small dipping-needle was submitted to its action and the following results obtained. The needle could move in the plane passing through the magnetic meridian of London.

2986. There was no deflection of the needle when the helix was in the plane of the magnetic equator, or in a plane perpendicular to that containing the mechanical axis of the needle. In every other position it affected it; so that these two planes divided the sphere of action into four segments, as before.

2987. As the helix passes from one quadrant to another, the direction in which the needle is deflected changes as before (2982.). If the helix is in the upper north segment or the lower south segment, the upper or south end of the needle is deflected towards the south; if the helix be in the upper south or lower north segments, the upper or south end of the needle is deflected towards the north. If the helix be carried round the needle in the direction of the plane of motion, which in this case is that of the magnetic meridian, the end of the needle starting from a mean or unaffected position will move first one way, as for instance, north and then south; north again and south again, and finally north to regain its place of rest: so that there are two extreme deflections of the end in each direction, as before, in the case of the declination magnet (2982.).

2988. In other words, when the helix was anywhere below the magnetic equator, the *lower* or north end of the needle tended to point outwards from it or outside of it, being as it were *repelled* by the axis of the helix, but *drawn* by the outer curved lines of force, fig. 20 (2992.). Or if the helix were above the equator, then the *upper* or south end of the needle went outwards from the helix, moving exactly in the same direction in relation to the helix as the lower pole did before.

2989. The support of the needle was turned round 90°, which therefore removed the plane in which the needle could move 90° from the magnetic meridian. This carried the plane of no action on the needle 90° round, so that it now coincided with the magnetic meridian; and the plane, which, standing east and west, was before neutral, was no longer a plane of indifference, but in fact passed at the middle of the segments through the places of strongest action.

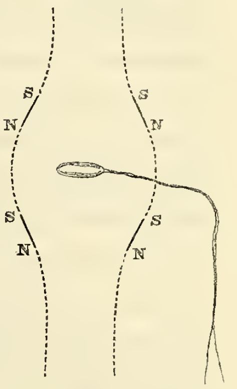
2990. Here, with *inclination*, as before with *declination*, it is not the direction in which the needle stands that determines what action the helix may have upon it; for it may be loaded or otherwise restrained, as all horizontal needles are; but it is the *direction* of the lines of force at the needle which, with the helix, governs all. The helix may be above or below the prolongation of the needle indifferently; for if it still continues on the same side of the line of force, under the influence of which the needle acts, then the end of the needle moves in the same direction, though it may travel towards the helix in one instance and from it in another.

2991. I suspended a needle so that it was free to move in every direction, and now I obtained the simple natural effect of the helix, or a diamagnetic globe (2877.) on a given line of force, and it is well to have it in mind. For, though we are obliged for the sake of practical observation to divide the position into two parts, declination and inclination, yet the results in each case are much better compared and remembered when the simple law of change in the whole line of force is ready in the mind for reference. The equatorial plane and the magnetic axis are now the only parts in which the helix can be without affecting the position of the needle;

the first gives places (for the helix) with a stable position for the needle, and the second such as have either stable or unstable positions, according to the helix distance.

2992. If the helix be out of the plane and axis, then the end of the needle nearest to it leans from it as if repelled. If the helix be carried round in a circle of latitude, the end of the needle moves round before it just like the upper end of the needles at Hobarton and Toronto, in respect of the sun, during the midday hours. Instead of moving the helix round the needle, we may carry the needle into different positions as regards the helix, and then fig. 20 will represent the result. A result exceedingly simple, and in perfect accordance with the diamagnetic disposition of the forces produced by the helix (2972.), as the two dotted lines indicate.

Fig. 20.



2993. As an expression of the facts for use in applying them to the explanation and illustration of natural phenomena, it may be said in respect of *declination*, that the helix being above the needle in a plane having dip, and therefore above its magnetic equator, if on the east of a needle having north dip, it will send the south or upper end west, or if on the east of a needle having south dip (being of course then itself inverted (2972.)), it will cause the north or upper end to pass westward; seeming to repel the end of the free needle or part of the line of force nearest to it. In reference to the *inclination*, it may be said, that the helix being above the needle, tends to send the upper end of the needle or line of force from it. If the helix is north of the magnetic axis, it will tend to send the upper end of the needle south; if it is south, the upper end will go north. As in the case of the declination, it is as if the end of the free needle or line of force nearest to it was repelled. In fact every case is included in this result, that if the helix be diamagnetically adjusted (2975.) for a free needle, whether it is above or below the needle, or on this side or that, the nearest end of the needle will be as if repelled, provided the helix is not in a neutral position.

2994. I repeated all these experiments with the helix reversed, so as to give the effect of a paramagnetic globe of air (2865. 2973.). I need only say, that the effects were precisely the same in nature and order, only in the *reverse* direction. They will be required in the explication of the night and early morning actions, due to the cooling of the atmosphere (3003. 3010.).

2995. In these experiments, that the laws of deflection might appear in their simplicity, the needle was suspended in the air, and the representation of the sun's action carried round it in all directions. But in nature the air is only above the needle, and the earth as a magnet is beneath it. In the natural case also, there is the fixation of the lines in the earth (2919.), which tends, by holding them below the surface, to give them an amount of deflection *at* the surface, far beyond what they would have if they were as free to move in the earth beneath as in the space above*; and though this deflection would coincide with that produced by the helix alone, still it was important to verify its effect. I therefore took a bar magnet 30 inches long, and weak in condition, and suspended the needle above it in various parts, so as to have the effect of north or south dip to any degree, or no dip at all near the middle parts. The effect of absence of air from beneath was also in a certain degree represented; and to make this point more striking, I occasionally put masses of iron on and under the middle part of the magnet. The results with the helix were now influenced greatly in the *amount* of the deflection, but not in the direction. When the helix affected the direction of the needle, it was according to the above laws.

2996. In the consideration of natural phenomena, the magnetic axis, and also the planes of the magnetic equator and meridian, being circles or planes of no deflection, are very important. Changing as they do with every change, either of place or declination or dip, they require some ready means of illustration, and can hardly be comprehended in their effects without a model. I have prepared a globe on which, after marking the places of the observatories, I have drawn the magnetic meridians of these places as they were last estimated. I have then in another colour drawn for each place its magnetic equator, making that a great circle parallel to the equatorial plane of the dipping-needle at the place. I have also marked on the globe the mean path of the sun for each month, and by the use of adjustible pins to indicate the hours before and after noon of any given place, I have the means of ascertaining with sufficient accuracy when the sun is in any particular quadrant, or what part of the quadrant; when it passes a neutral line, and what its position in relation to the place of observation is, in a manner which no diagrams or figures could supply. I have found the globe very useful; and I accustom myself to place it always in a certain position, namely, with the axis of rotation horizontal, the north pole to my right hand, and the astronomical meridian of the place of observation towards the zenith. The observer can then regard it as from the place of the rising sun.

2997. Though we thus have the experimental conditions of a needle under an action like that resulting in nature from the presence of the sun (2920.), I do not pretend that they can be applied without modification to natural phenomena, but only that they give very important aid in the study of the latter and the rationale of their action. The atmosphere, instead of being illimitable, wraps the earth round as a garment; the influence, as it extends from the region of action, must, in respect of that portion which is conveyed through its mass (2920.), curve with its curvature, and give a result in any particular place, which only refined calculations founded upon careful observations can determine accurately. In regard to the development of the air action, it would, I think, be very interesting to ascertain, even roughly, the daily variations of a magnet at the bottom of a deep mine, half-way up, and at the mouth of the shaft. The results might tell us much about the holding power of the earth and the depths to which the deflections of the magnetic lines of force penetrate, and might even give us a rough expression of the changes of the internal power (or the absence of such changes) when freed from those dependent upon the atmosphere.

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* Referring to the typical globe of cold air (2874.), it is manifest that if the space below the horizontal lines *a*, *c*, &c. were occupied by matter holding the lines in it, then the deflections now represented on the lower parts would appear above the holding surfaces, and to a much greater degree, though extending downwards to a much smaller space.

2998. Another reason why the experimental results must not be applied too closely is as follows. If the lines of force of the earth were perfectly regular, then the change produced amongst them by the sun and air would be regular also. But as the natural system is not regular either between the tropics, as at Sister's Walk and Longford in St. Helena, or in the higher latitudes, as at Hudson's Bay, so apparent inconsistences may and must result. The probability is that the greatest irregularities in the arrangement of the earth's magnetism are in and near the surface of the earth, and that above they tend to adjust with each other into a more regular order. Still the irregularities must extend their influence very far upwards, so that the contortions of the magnetic meridians or lines of force are not likely to be effaced, or much diminished, at the region coinciding with the place of the atmosphere's effect.

2999. But though the lines are irregular in the large space affected by the sun, the result will be expansion of the whole as a system and diamagnetic polarity. The lines of force below will be affected by those above; and so, though a perfect similarity between different places is not to be expected, still the kind of change at the earth's surface is not likely to be so uncertain as it might at first appear. Therefore I believe the globe (2996.) will be found very useful in giving information regarding the probable effects at the magnetic meridian and equator, due to the place of the sun in the two chief quadrants for any given month of the year, or hour of the day.

3000. The passage of the magnetic meridian is important, and appears far more so after the experiment described (2978.) than it did on a former occasion (2942.). Being very often inclined to the astronomical meridian, it must have great influence in deciding when the daily declination changes in its direction. The place of greatest action, and its travelling north or south along a line of magnetic force according as the declination was west or east in relation to the helix as a sun, was confirmed by an experiment; and the further observation (a consequence of the former), that when the sun was equidistant from a place more north or south than itself, its action was far stronger on that side at which its path and the declination direction made an acute angle than on the other side where it was obtuse, was also confirmed. Thus if the helix, moving from east to west, were passing a place north of it having western declination, then the action was stronger on the western side of the place than on the east for equal distances of the helix from the magnet.

3001. The passage of the magnetic equator by the sun is also important, since the direction of the diurnal variation of the experimental needle is then altered; and this is of the more consequence, because by the great degree of natural declination in many places, even far north and south, this passage is thrown forward towards the astronomical meridian, either on the east side or the west, and comes into effect during the more influential hours of the sun or the cold. In all those places too where the dip is little, as at St. Helena, and in or near the sun's path, it may be important in influencing the amount of action. From the change of place of the sun between the tropics, and the variety of dip and declination at different places, the passing of the neutral planes by the sun and acting region must take place under an extreme variety of conditions; the unravelling of which I think will be much assisted by knowledge such as that which the preceding experiments and principles give. The sun may be astronomically either north or south of the needle, and yet the declination of the needle not change in direction (2980.); or if there were much mean declination, as at Greenwich, then it might be astronomically east or west of it, and yet the declination produced not change its direction. The sun region may be south of a place and yet send its upper end further south (2990.); for all will depend upon its position in relation to the magnetic meridian and the magnetic axis, which are in most cases very far removed from those that are astronomical: added to all these causes of variety, there is the fixation of the lines of force in the earth (2919.), which tends to give a further diversity to them.

3002. In the former paper I considered only the effect of air raised in temperature above the mean condition (2895.), illustrating it by the sun's effect in the middle of the day; *now* I purpose considering that which will be produced by the cold of night, which reduces the air of a given region below the mean air temperature of that place. When a portion of air is so cooled, its conduction power is increased; in conjunction with the warmer air of surrounding regions it deflects the lines of magnetic force passing through both, as indicated by the type globe (2864. 2874.), and acquires what I have called conduction polarity (paramagnetic), meaning thereby simply that the lines of force draw together in the middle of the cooled air.

3003. Theoretically, the effect of a cold region of air coming up from the east would be to make the magnetic lines of force, as they leave the earth, advance or bend towards it, because those in and about the cold air are inflected into it; and as those immediately west of the cold region move into or towards it, so those further west, being in part relieved from their tension, will also move east, and thus an effect, the reverse of that of the sun (2877. 2972.), or the same as that of the helix in the paramagnetic position (2973. 2994.), will be produced. The upper ends of needles at places having dip show this deflection of the upper part of the lines of force, because they move by, with, and in them.

3004. So as cold approaches, the lines will lean towards it until it is in the position of maximum action in the eastern quadrant; then they will return (in declination) before the cold, until both it and the line (or needle) are in the magnetic meridian; after which, as the cold travels on westward, the needle will follow it west until the cold has attained its place of maximum action in the west quadrant (2982.); and then, as the cold retreats, the needle will return east to its mean place; assuming that there is no other action for the time than that of the cold region. The upper end of the free needle, therefore, at any given place will tend *towards* the cold region, just as before it tended *from* a warm region; and as the declination is affected, so also the inclination will be. If the cold be on the magnetic meridian of a place within the tropics, as St. Helena or Singapore, it will increase the dip there, whilst at the same moment it is diminishing the dip at places south or north of it having considerable dip, a result which follows directly from the inflection of the lines of force into or towards the cold region.

3005. The chief regions of heat and cold on the same parallel of latitude, do not follow each other at equal intervals of time. It is difficult to make a judgement regarding their interval in the atmosphere above; but the maximum of cold on the earth for the twenty-four hours, is assumed by many as being seventeen hours after the preceding noon, and only seven hours from the coming noon. This brings into consideration the joint effect of hot and cold regions in deflecting the lines of force, especially during the forenoon and middle of the day. If a cold region be only three and a half hours west of a place at the same time that the warm region is three and a half hours east of it, it is very manifest that the joint effect of the two, for both act then to cause the same deflection, will be far greater than that of the heat or cold alone, or than any corresponding effect at other periods, for neither twelve hours after, nor at any other time, will there be an equivalent condition of circumstances; and so it is also for other combinations of hot and cold regions, the effect of which will vary both by position and by their extent. A free needle is held in tension by the lines, which are themselves governed by the hot and cold regions of atmosphere; it probably never occupies its mean place, but is always in the resultant of these ever-present and ever-varying causes of change.

3006. As the earth revolves under the sun, each place would have, speaking generally, a maximum and a minimum of temperature for its atmosphere in the twenty-four hours. But looking at the globe as a whole, there would be one maximum and two minima, *i. e.* there would be a maximum region somewhere beneath the sun in his path, and a minimum in each of the polar regions; which, as regards the twenty-four hours, would not be at the pole, but in some place of high latitude, and perhaps, as before, seven or eight hours before noon. These cold regions will be very seriously affected in their extent and place and power by the position of the sun between the tropics; for as he advances to one tropic the cold region there will diminish in extent and force, whilst the other will grow up in importance; and whilst they thus vary in their power of influencing the general direction of the lines of force, they will vary in their own position also, and have at different times very various relations of place to the sun in different months, and so produce very various effects. It is these differences which are made manifest to us, as I believe, in the night and morning actions at the numerous observatories scattered over the globe.

3007. I will proceed to apply these views, and the additional knowledge gained by experiment, to the localities formerly considered, and to some new ones between the tropics, for the purpose of explaining, if I can, the principles of night action; of retardation, more or less, of the effects in relation to local time; of the difference in direction of the declination variation in different months, for the same place at the same hours, as pointed out by Colonel SABINE; of the diminution of dip in one place, and increase of it at another for the same local time. In doing so, it will be necessary to refer continually to that place which may be considered, in respect of the station, as the centre of hot or cold action for the time. I will endeavour to use the word region for that purpose, meaning thereby not the whole extent of heated or warmed air, nor the centre, but the chief place of the altered portion. It is very manifest that in some days in March or September, *all* the air that is east of the meridian at 21^h or 22^h may be considered warm in comparison of that which is then west of the same meridian, and that a resultant of action, which shall be the same for all places, cannot exist.

3008. We are to remember that the eastening and the westening of the upper end of the needle, of which I always speak, is produced in two ways. The needle travels as positively by the withdrawal of a direct cause of action as it does under the immediate direct action of that cause, but in the contrary direction (2982.). A westening may be the result either of the coming up of the sun on the east of the place of observation, or of its withdrawal in the west, after he has passed over the meridian and produced the great east swing.

3009. *St. Petersburgh* has a mean declination of 6° 10′ W., and a dip of 70° 30′ N.; therefore, though the magnetic and astronomical meridians are not very oblique to each other, still the sun or warm region reaches the former from 20′ to 40′ before the latter, and hence the time of the great sun-swing, which is from 20 to 1 o'clock, is made earlier than it otherwise would be. The magnetic equator of the needle (2977.) forms an angle of about 40° with the earth's equator, and being thus tilted, it disposes the two quadrants chiefly concerned in the daily variation (2979.), so, that in the St. Petersburgh summer the warmest region is not only far nearer to the needle, but passes through the strongest places of action of the quadrants, whereas in winter it is further off, and also in much weaker positions. Hence a cause, as I believe, of the great difference in the amount of variation of declination, and also in its character: in November, December and January, it is from 4′·47 to 4′·65 only, whilst in June it is 11′·52*. See the Tables, p. 82, and the Curves, Plate II.

3010. In December or January, being St. Petersburgh winter, the sun-swing east

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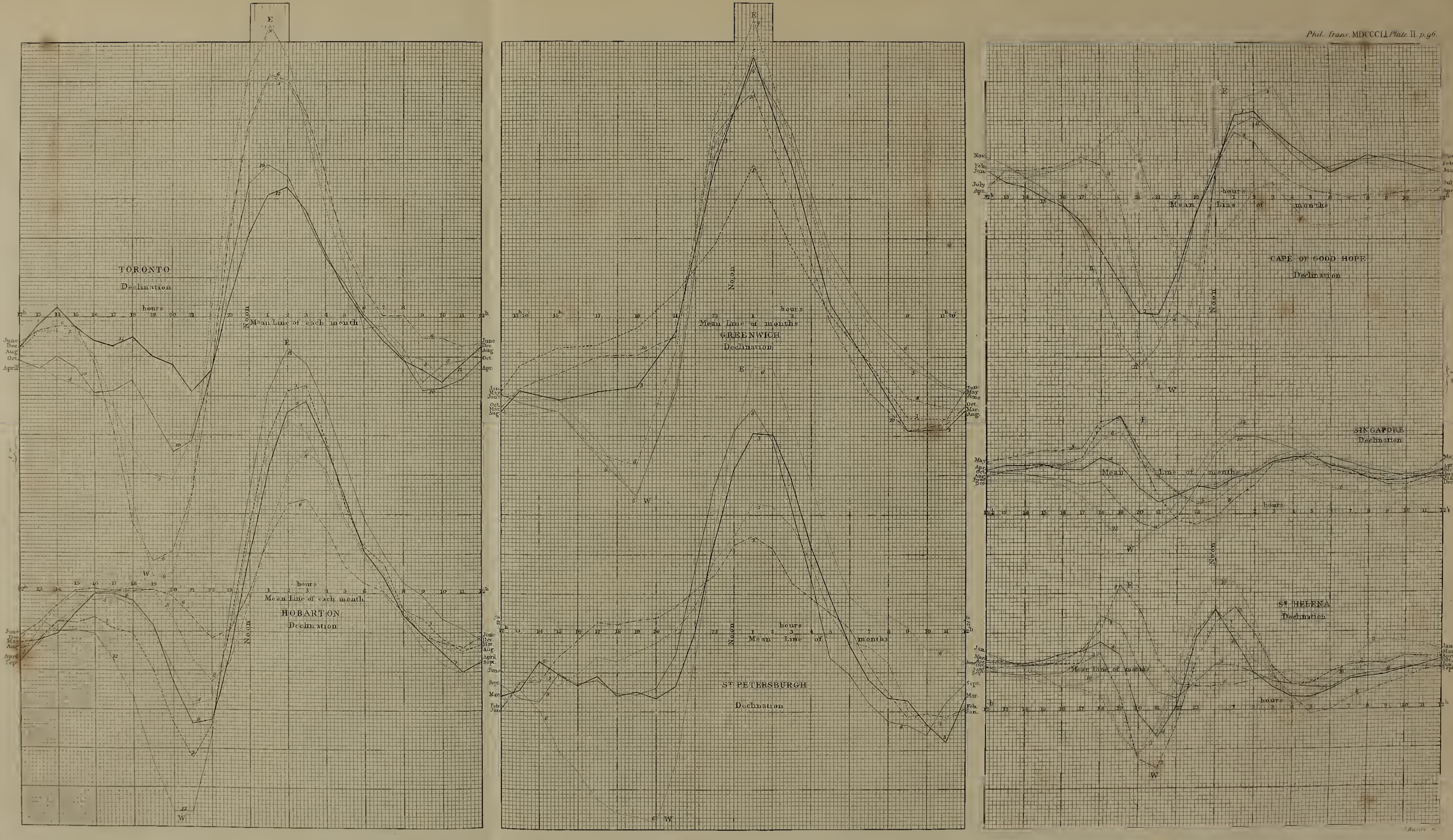
* The eastening and westening of a free dipping-needle are not properly represented by the movements of a horizontal needle, inasmuch as at places with different dip the angle is read off on planes differently inclined to the dip itself, and in high latitudes the effect is greatly exaggerated. But though different places may not be compared without a correction, the variations for the same place as St. Petersburgh are comparable and proportionate.



Eastern positions of the upper end of a free Needle are indicated when the curves are above the Mean Line of the months, and Western positions when below.

almost disappears. It is over by 1 o'clock*, after which the upper end of the needle follows the sun until 9^h, having passed its mean position at 5^h. It then stops, after which it moves east until 16^h or 17^h; then again stops, or nearly so, until 21^h, and then the sun-swing comes on, carrying it to extreme east. So here there are two very important points to explain, namely, why the needle moves eastward after 9^h, and why it does not travel westward from 13^h to 20^h, but, on the contrary, is travelling eastwards or standing still: the explanation, according to my view, is as follows:—St. Petersburgh is a place in which, from its position, the upper cold, consequent upon the daily withdrawal of the sun, would produce a paramagnetic action (2994. 3003.). This action, as the sun set, would begin to appear on the east, and I conclude that at 9^h–11^h the cold region coming up from the east, not on the latitude of the sun's path, which is far to the south, but probably near to that of St. Petersburgh itself, is able at 9–11 o'clock, during which the needle is stationary, to counteract any remaining tendency westward, and after that to draw the line of force and the needle end eastward until 17 o'clock, and to hold it there, after which the sun sends it eastward in the great swing. That the cold, considering its probable position, may well direct the needle end eastward till 17^h, and the sun region not send it westward from 17^h to 20^h or 21^h, is seen, I think, to be a very natural consequence of the probable position of the two regions between these hours. For letting the sun (whose place we know) represent the warm region at 17^h, he is then in the eastern quadrant below the horizon, so that if he could affect the needle through or round the earth (2995.), it would be to easten it, and it continues in that quadrant until 19^h. Then at 19^h, when he enters the quadrant, in which he begins to exert a westening action on the sun, he is in such a position as respects the needle at St. Petersburgh (as is seen by a line drawn over the surface of the globe (2996.) and compared with the magnetic meridian and dip), and in so inefficient a part of the quadrant (2982.), and also so far off, that it has no power to send the needle westward, but only in association with the retreating cold region to hold it there, until at 21^h, or thereabout, the sun-swing from west to east occurs as in other cases. After this the needle follows the sun from 1 o'clock, being, as the hours advance, gradually arrested and taken up by the cold region of the next twenty-four hours, as already described.

3011. I have considered the cold eastening as continued until as late as 17^h, which would imply probably that until that hour the cold region was east of St. Petersburgh. It is very difficult to speak, even in a general manner, of the places or times of things so little identified as yet, as the warm and cold regions in the upper atmosphere; but referring to the temperatures on the earth at St. Petersburgh, I may point out, that the extreme cold is, in the month of January, as late as 19 and 20 o'clock, and *five hours* later than it is in the summer months. I may also point out here, for use in the summer months, that the maximum heat varies three hours in the *opposite direction*; so that whilst from the highest to the lowest temperature in the day is only eleven hours in summer, it is nineteen hours in winter, as may be seen by the Temperature Table, p. 83. As the day comes on, therefore, in January the highest temperature is only five hours after the lowest, which accords generally with the assumed cause of the effects on the needle*.

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* The St. Petersburgh observations are at $21\frac{1}{2}$ minutes after each hour; but I mention the hour without the minutes as sufficient for a general statement.

3012. As I am endeavouring to make St. Petersburgh a general case of night action for the explanation of corresponding effects at other places, so I may notice that the night action must contain a portion of sun effect which combines with that of the cold. The action of the sun is known by observation to be very extended; in the case of St. Petersburgh, the sun, when at the southern tropic and on the meridian, is between 80° and 90° from the station, and yet we see by the observations and curves how large an effect he produces (3009.). Wherever the sun may be, he is by his motion causing changes which are felt simultaneously over the whole globe; and at 9 and 10 o'clock he is in an effectual part of that quadrant which would send the needle eastward if the earth were replaced by air, and in the representative experiments with a helix (2995.) does so send it eastward when a magnet is interposed. The night action ought therefore to be greatest in winter, as it is, because the cold is then most intense, and also because the action of the distant sun coincides with it. It is very probable that many of the curious contortions of the night action which appear in the curves of Hobarton, Toronto and elsewhere, may depend upon the manner in which, at different hours, these two causes (probably with others) combine together.

3013. Though the declination varies little or nothing between 17^h and 21^h, no westening then appearing (3010.), still I should expect a marked action on the inclination at that time, and conclude that it will be on the increase; but I have not been able to obtain a table of the daily variation of inclination.

3014. In the month of February the same remarks apply; but as the sun is now coming from the southern signs and drawing nearer to St. Petersburgh its power is increasing, and this is shown by making the cold eastening for 15^h, 16^h and 17^h less in extent than before by more than half a minute (of a degree), and by absolutely overcoming it and making a return westwards between 17^h and 18^h, before the swing to the east comes on. In March the effect is still more striking; the paramagnetic eastening is arrested at 14^h, and the following diamagnetic westening extends to 20^h; then follows the swing. In April the westening by the warm region is as early as 13^h and continues to 20^h, being very strong. It is interesting to look at the Table of Temperatures for these months, even as they are obtained at the earth's surface. As the months come on the eastening from the cold ceases sooner and sooner, being in January and April 17^h and 13^h respectively. The minimum of temperature also retreats, being for the same month 20^h and 16^h. On the contrary, the maximum of heat *advances* from the winter to the summer months, being also greatly increased; and the effect on the sun-swing is seen both in the *advanced* time of change and the *increased* amount of variation.

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* In relation to the cold of the upper atmosphere and the occurrence of its maximum (at certain levels at least), not at midnight but hours after, how often do we in this country see a clear bright night, and then just before the sun rises, the formation of a veil of clouds high up, and, upon his appearing, their dissolution and passing away! In these cases the clouds show the time of greatest cold above by their formation, and by their dissolution its quick reversion and change into increasing warmth.

3015. In May and June the night or cold eastening has disappeared, or is shown only by a little hesitation; and from midnight the coming on of the sun region sets the needle end west. If we look at the globe (2996.), we should be led to expect that it would do this. The sun is then in the northern tropic nearly, wheeling round St. Petersburgh and comparatively near to it; and a free dipping-needle would in twenty-four hours make one revolution in the same direction as the sun region, but at the opposite end of the line, joining the two together. If the needle were at the astronomical pole of the earth, having great dip, it would describe almost a circle with nearly uniform motion; but being really much nearer to the warm region in one part of the uniform daily course of the latter than another, the radius vector joining it with the region then makes a much greater angle in a given time than when it is further off, and hence the greater rapidity of the motion between 20^h and 1^h, and the production of what I have familiarly called the sun-swing from west to east.

3016. It will be seen from the Table of Curves (Plate II.), that we have at St. Petersburgh a fine example of that kind of result which Colonel SABINE called attention to so strongly in his paper upon the St. Helena phenomena*; and those occurring at Hobarton, Toronto and elsewhere; namely, a declination variation in *different* directions for the same hours in different months. Thus, in the present case, the needle end goes eastward for the hours 13^h to 20^h in October, November, December, January and February, whilst it goes west for the same hours in April, May, June, July and August: March and September curves fall midway. But this difference is now I hope by the hypothesis accounted for (3010. 3015.), and I trust that equally satisfactory reasons will appear for St. Helena (3045.) and other places (3022. 3039. 3065.).

3017. The paramagnetic character of the eastening effect by cold in the winter months after 10 o'clock, would probably be illustrated by inclination observations for the same time; for if the cold region passes to the south of St. Petersburgh the inclination will be decreased by the paramagnetic action, but increased by the diamagnetic resultant; and the manner in which these two elements of direction, *i. e.* inclination and declination, are combined at any given moment, is very important to the full elucidation of the magnetic effect of the atmosphere. I have not been able to give these data for St. Petersburgh. The total force variations would also help greatly to clear up the subject. Indeed it is not fair to endeavour to explain the results of the assigned cause by taking only one element of three into consideration. What we require ultimately to know, is all the changes of a free needle in position and in respect of power. All are important, and all should be considered at once. I presume that the theory of the variations cannot advance very far without their joint consideration.

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* Philosophical Transactions, 1847, p. 51.

3018. *Greenwich* presents a fine case of the night episode, and the different directions of the magnetic variation for the same hours in different months. In these respects it is very much like St. Petersburgh, but has great additional interest, because of the large western declination*, and the effect produced by it on the places of the active quadrants (2979. 3000.), and the times of the variation phenomena. On setting up its position on the globe (2996.), it will be seen that the equatorial plane is not likely to be much concerned in the midday action, and that the sun or warm region passes nearly across the middle of the two chief quadrants in summer; which with its nearness at the same time, ought to make the midday swing to east very great. In winter it is further off and in much weaker parts of the quadrant, so that the swing ought to be far less, and such is the case. The greatest summer variation is 11′·30, and the least winter variation only 5′·88. In April, May, June, July and August, the great west declination of the south or upper end of the needle is at 19ʰ 20′, and the chief east position at 1ʰ 20′. The latter position remains the same all the year round, but the extreme westening is in the other seven (cold) months at 9ʰ 20′ and 11ʰ 20′†, or verging towards midnight; it then surpassing the morning west deflection. Thus the sun's effect in summer, in weakening the cold night effect (3005.), is very evident; and so also is the manner in which the night action grows up, until very prominent, in the winter months, through the strengthening of the cold action (3006.), when the sun is towards the southern tropic and in the weaker parts of the segments. The assumed principles of this action have been already given in the case of St. Petersburgh (3010. &c.).

3019. The magnetic meridian is much to the east of the astronomical meridian, where the warm region passes it, especially in winter, for then the sun crosses it about 10 o'clock, and in summer about 11 o'clock. Hence the swing ought to be earlier in winter than in summer, though, because of the slower angular motion of the warm region in relation to Greenwich (3015.), it ought then to occupy a longer time; and yet, as above said (3018.), be, by reason of distance, of smaller amount. All this appears to accord remarkably with the fact. The swing begins at 17ʰ in the winter but not until 19ʰ in the summer, and ending at the same hour at both seasons, namely, 1 o'clock, is much longer in its occurrence in winter than in summer. It begins earlier, because the magnetic meridian is sooner passed than in summer; and the reason also appears why the extension in time is at the beginning rather than at the termination of the swing; for, because of the declination, the warm region is at the same hours much less east of the magnetic meridian in the morning and much further west of it in the afternoon, in winter than in summer; hence the swing is thrown forward in time in winter; and though prolonged, its termination coincides with the termination in summer, as far at least as these two-hour observations can indicate.

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* Mean declination 22° 51′ W. Mean inclination 69° N.

† See the Curves, Plate II. The observations are only for every two hours, so that no degree of nicety can be expected in assigning the time of any given change.

3020. As the region precedes the sun, the degree of mean declination here ought to make the day-swing come on early, *i. e.* earlier than at Hobarton, and especially earlier than at Toronto, unless other causes of variation interfere. Now the beginning is earlier than at Toronto, but the end the same. Both the beginning and the end is an hour earlier than at Hobarton. The latter difference I believe due to the difference of mean declination: at Toronto, I think we shall find another cause influencing the time (3032.).

3021. We are to remember also that in winter the sun or warm region passes the magnetic meridian two hours before he passes the astronomical meridian; and therefore his effect in giving west position to the south or upper end of the needle ceases long before it does in summer, and perhaps even before it ceases to come nearer; and so the eastern after-effect on it ought to be greater, which it is. This eastern effect should be strengthened also, because the action of the warm region on the needle ought to be comparatively great after passing the magnetic meridian; for its path forms an obtuse angle with the meridian before the passage and an acute one afterwards (3000.), and therefore is more powerful. To all these causes of action will be added the effect for the time of the cold in the distant west (3005.).

3022. The case of difference of direction before 19^h (3016.) is very marked at Greenwich, as may be seen by looking at the Curves for the months, Plate II. The south or upper end of the needle goes west in May, June, July and August, from 12^h to 19^h, *i. e.* from midnight to five hours before noon; but in October, November, December and January, it is eastening at the same hours. Considering first a summer month, as June, the upper end of the needle is westward as the sun comes onward (as it ought to be) until 19^h, when he is almost in the middle of his passage through the east quadrant; and in respect of distance and angular relation to the magnetic meridian, the warm region is then, probably, in the place of greatest power to produce westening of the needle end*. In the next six hours the needle passes to extreme east, performing, according to the observations, a fourth of the whole swing in the first two hours, a half in the next two, and a fourth in the remaining two, the journey being no doubt with first rapidly increasing and then rapidly diminishing velocity. In this transit of the region, the sun is for about two-thirds of the time in the eastern quadrant, and one-third in the western; and his path in the latter third forms almost the base of an equilateral triangle with Greenwich, having the magnetic meridian for one side, so that all that time it is close to and therefore has strong action on the needle (3000.). The sun is at 1^h in such a position as respects this angle, that if

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* It must not be forgotten, that the return from an extreme east or west position is not when the sun or warm region passes by a neutral line, or from one quadrant to another, but when it passes its point of greatest action in a quadrant (2982.).

we assume the region to be somewhat in advance of it, the latter would be in that place where it could exert its maximum eastening effect; and therefore after that, as it recedes westwards, would let the needle return from east to west, as it does, following it. The needle continues to go west, passing its *mean* place for the month about 7^h; in the meantime, before that, at a little after 6 o'clock, the sun has left the western segment by passing the magnetic equator; it has not yet set to Greenwich, and if it have any action, it will, because of the segment it is now in (2979.), still be to carry the needle end *westward*. The end in fact continues to go westward, slowly only, after 10 o'clock, gaining a little from 10^h to 15^h; and then, as the sun comes up, passing more rapidly west, as it ought to do, until 19^h, and finally making the great swing to the east as before. The whole progression here is very simple, and apparently a natural result of the assumed cause. Effects of cooling no doubt come in; but the cold region has diminished in intensity and extent (3006.), has retreated northward, and its action appears in combining with the former to produce only variations in the velocity of the change.

3023. Then for the winter, let us consider January; and, as the eastening is a maximum in all the months at 1 o'clock, after the sun's passage across the meridian, let us begin the cycle there. At 1^h the upper end of the needle is at extreme east, and the amount of the variation not half what it was in summer, the sun being now far off. The sun and warm region pass the magnetic meridian about 21^h or 22^h; and therefore, in the hours before and after that, should produce the full west to east effect. At 1 o'clock the needle returns west, following the retreating sun, and does so quickly for seven or eight hours, or up to 9^h, during which time the warm region, and also the early morning cold region, are in quadrants and positions, which, if they have any action at all like that referred to in the experiments (2975. 2995.), would then set or hold the needle end west of its mean position. Then an action of the following kind supervenes; the needle remains stationary until 11^h, after which it goes east at midnight and until 15^h; again remains stationary, or nearly so, for two hours; then eastens again, slowly at first and afterwards more rapidly, until 1^h, when it has attained its maximum eastening and the place from whence it set out.

3024. This night action is another case of the action of a cold region like that considered in respect of St. Petersburgh (3010.). It appears to me that at 11^h the immediate sun action and returns west after it, were over; that the cold region which was coming round from the east did then act by its paramagnetic condition (combined with the complementary effects of the sun's action on the other side of the globe), and set the needle eastward, as it would be competent to do (2994. 3010.) until 14^h or 15^h. In eastening, the needle does not arrive at the mean place, but is still 1′ west of it; and the reason why it hangs there from 15^h to 17^h and then begins to go east again, more and more under the sun's action, is probably that, as the sun rises in the southern tropics, his distance and position bring the resulting distant warm region gradually into action with that of the nearer cold; that at first he stops the action of the latter, and then as he advances combines with and finally replaces it; causing the usual swing to come on, slowly at first and then quickly, from west to east by 1^h. How this would happen is well seen, both as respects the place of the sun in the southern hemisphere, and in the two magnetic segments, by reference to the globe (2996.) and the diagram of the curves of variation, Plate II.

3025. Considering another and an intermediate month as March; at 1^h the upper end of the needle is at extreme east; then until 9^h it follows the sun as before (3023.). From 9^h to 11^h it is stationary; then the paramagnetic action of cold from the east occurs, and the needle moves east until 13^h. It is then stopped, and two hours sooner than before; for the sun now appears to Greenwich as early as 6 o'clock, and in a more favourable position for effect, both as regards the magnetic meridian and the segment in which it has for the time its place; and so the needle is actually sent west for a couple of hours. It is then almost held steady until 19^h, after which the great sun-swing occurs. The holding west and yet the absence of more westening between 15^h and 19^h, is not inconsistent with the southern place of the warm region, and it is probable that at that time the *dip* is increasing; an effect which would accord very harmoniously with the condition of matters at the time.

3026. Other months are on this or that side of March in respect of their effects; the corresponding month on the opposite side of the year (September) is the same as March, except in that portion of effect which is consequent upon a month following one that is warmer or colder than itself (3053.). Greenwich therefore satisfactorily illustrates the application of the hypothesis to the case of a difference in direction for the same hour in different months (3016. 3022.); and also the occurrence of the night effect, and its transition into the very marked eastening of the early morning.

3027. The cases of *Hobarton* and *Toronto* are so similar, though in opposite hemispheres, that they may be considered together. A very important comparison of the phenomena at both places has been already made by Colonel SABINE in relation to the variations of declination, inclination, and total force*. When examined by the globe (2996.) the distribution of the quadrants is nearly alike, the sun being in two chief east and west quadrants, from about 18 to 6 o'clock, or during the day. The sun is in more influential parts of the quadrants in summer than in winter, and the effect is seen in the difference of the amount of declination variation. At Hobarton it is 12′·05 in summer and only 3′·6 in winter. At Toronto it is 14′ in summer and 5′·2 in winter. The night action at both is alike in character, and has been sufficiently explained according to the hypothesis in the former cases (3010. 3024.).

3028. Colonel SABINE has given the data by which the variations of the inclination and of the total force at Hobarton and Toronto may be compared with and applied to the hypothesis; but I hesitate to enter upon them in this general view, inasmuch as these and the declination variations should be closely considered and compared together at every hour for each particular place. The inclination variation at Hobarton is greatest in its summer, being then 2′·18, and least in winter, or 1′·28, as was to be expected. The great variation occurs in the daytime, as with the declination; the dip being most as the sun region passes over the meridian. The greatest dip is not at the same hour for all the months; it occurs at 23 o'clock for December, February and March, at 24 o'clock for September, at 1 o'clock for June and July; as it moves on so do the points of least dip on each side of it, so that the whole curve advances in time in the order of these months. There is also another affection of it, for the *quickest* transition is from *most* to *least* dip in some months, as December, February, and from *least* to *most* dip in other months, as June, July, September. At Toronto the dip variation, though peculiar in some points, may be said to have the same general character.

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* Hobarton Observations, 1850, vol. i. p. lxviii., &c.; also Philosophical Transactions, 1847, p. 55, and 1850, pp. 201, 215, &c. See the Curves, Plate II., and Tables for Toronto, pp. 80, 81.

3029. For the variation of the total force at both places, I will at present only refer to Colonel SABINE's volumes, and the observations he has made thereon.

3030. There is a remarkable difference between the time of the day changes at Hobarton and Toronto, to which Colonel SABINE has called attention. It consists in the occurrence of those at the latter place, about an hour before those of the former. If this had depended upon the declination, then the change should have taken place first at Hobarton, for there the sun arrives at the magnetic meridian before he comes to the astronomical meridian, and for like hours of local time he is in a better position in the quadrant in the afternoon than at Toronto; still it is the later of the two.

3031. If the *time* of the sun-swing from west to east be considered, the middle of it ought to be somewhere near the period when the warm region is passing the magnetic meridian (2982.), and in that way supplies an approximative expression of the relative positions of the region and the sun. The swing is at Hobarton from 21 to 2 o'clock, or five hours, and the magnetic meridian is passed by the sun nearly in the middle of the time, or $23^h\ 20'$ o'clock. But according to the supposition just made, this is also the time at which the warm region ought also to pass, and so the sun and the region in this place appear to arrive at the meridian together. At *Toronto* the sun-swing is about four hours in winter, or from 21 to 1 o'clock, and five hours in summer, or from 20 to 1 o'clock. Of the latter five hours the middle is 22½ o'clock, at which time the region ought to pass over the magnetic meridian, and as that coincides nearly with the astronomical meridian, it appears that the region is about 1½ hour *before* the sun. By a similar comparison for winter, the region would then appear to be about an hour before the sun*.

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* In reference to the position in advance of the sun, of the resultant of those actions which set the needle end westward, we must remember that the preceding cold, being perhaps seven hours only to the west, is by its action on the general system of the curves aiding the westening of the needle, whilst the sun is in the east and even over the meridian (3005.).

3032. I am inclined to refer much of this precession of the warm region at Toronto to the geographical distribution of land and water there. The Atlantic is on the east and the continent of America on the west of the station, and as DOVE's charts and results intimate, the temperature may rise higher and sooner over the land than over the water, and so throw the warm region in respect of Toronto in advance of the time or of the sun. In the case of Hobarton the arrangement is different; and, in fact, what land there is is between the advancing sun and the station, and would tend to hold the warm air region back, and tend to cause its time to coincide with that of the sun. Even the greater difference in summer than in winter at Toronto appears to be explicable in the same manner, by reference to the relative position of the sun at the two seasons to the land and water arrangement.

3033. Though the temperature on the earth's surface is a very uncertain indication of that above (2937.), yet as far as it goes it harmonizes with this view. The maximum temperature occurs sooner after midday at Hobarton than at Toronto; in the former place it is at 2 o'clock and very regular, and the minimum at 16–19 o'clock, being earlier in summer and later in winter. At Toronto the maxima are from 2 to 4 o'clock, and the minima at 16–18 o'clock. The maxima are later in summer than in winter; the minima are as at Hobarton, being later in winter than in summer. The mean temperature is lower at Toronto than at Hobarton, being as 44°·48 and 53°·48: the range of variation is also greater, being at Toronto 43° and for Hobarton only 18°.

3034. It is probable that effects of retardation and acceleration, in respect of the passage of the local part of the warm region for a given place, may occur in many parts of the globe, and these will require to be ascertained for every locality and for the different seasons there. A place having the reverse position of Toronto would have a reversed or retarded effect; and hence it might happen that needles in the same latitude might be affected at very different local times, and yet all be regularly affected every twenty-four hours. The region would in that time make its diurnal revolution, but vary in the velocity of its different parts at different periods of its journey, and that in a different degree and order for different latitudes, and for different parts of the same parallel of latitude. Even the time during which the effect (as for instance the sun-swing) continued would probably be altered; one place holding the influence longer and another dismissing it sooner, analogous to two conditions of stable and unstable equilibrium.

3035. *Cape of Good Hope**.—This station is in longitude 18° 33′ east and latitude 33° 56′ south. The mean declination is 29° west and the dip 53° 15′ south. The amount of dip, combined with the position of the place, gives a magnetic equator, which passes nearly through the astronomical poles, and so the sun's path in every part of the year intersects it almost at right angles and at the same hour, namely, about 20′ past 7 o'clock in the morning and evening, or at 19^h 20′ and 7^h 20′. But because of the great declination, the sun is in the astronomical meridian two hours before he arrives at the magnetic meridian in Cape winter, and half an hour or more before in Cape summer.

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* See Tables, pp. 117, 118, and curves of variation, Plate II.

3036. The sun passes obliquely through both the chief quadrants and across their central parts pretty equably; but because of the western character of the mean declination he is much nearer the Cape when in the eastern than when in the western quadrant for all the months, and so the coming up effect, *i. e.* the westening before the midday swing commences, ought to be more powerful than the eastening after it is over, and such is the case. This is in beautiful and striking contrast to Greenwich, which, having the same kind of mean declination and nearly in the same degree, is on the north of the sun's path, and therefore the luminary passes its magnetic meridian before 12 o'clock, and for a time still approaches the station: the result is the reverse effect to what we have at the Cape; for the eastening effect at the end of the midday swing is more powerful than the westening effect before it, as is well seen by the curves given in Plate II.

3037. Selecting July as the month in which the effect of winter occurs at the Cape, we find that the day-swing is very feeble, as it ought to be, the sun being in the northern tropic and far away; and the swing east is at an end by 3 o'clock, when the sun has passed by about one hour over the magnetic meridian. The upper or north end of the needle then westens for two hours, following the sun until 5^h, when the luminary is low to the Cape and at its setting. After that the needle end eastens slowly until 10^h, then a little more quickly until midnight (passing the mean position at 11^h); quicker still until 16^h or 17^h, and still more quickly until 19^h, when it has attained its maximum east position. This effect I believe to be due to the cold, which in these hours is approaching from the east, and setting by its paramagnetic action (3003.) the needle end eastward. On the surface of the earth the maximum cold in this month is at 17^h or 18^h, and as far as it goes this result accords with the effect above described. At 19^h, the sun in rising not only stops the eastening but quickly drives the needle back again, and the latter very rapidly goes westward until about 23^h, at which time the sun-swing from west to east comes on, being over by 2^h or 3^h, completing the daily variation, after which the needle goes west, following the sun as before. In this sun-swing is seen the effect of an inclined magnetic meridian (3000.); for though the sun is, at the beginning, only an hour east of the astronomical meridian, he is full three hours to the east of the magnetic meridian. As the swing occupies about four hours, the warm region is probably near the magnetic meridian about half-past 12 or 1 o'clock.

3038. *January* presents a case of Cape summer. The day-swing is then from 21^h to 1^h or 2^h. After 2^h the needle upper end follows the sun westward until 6^h, and then moves a little eastward for two hours; after this it moves slowly westward again, the whole effect being as if a cold region had occurred on the east, had passed over and gone away west, and the temperature below at this time is within 2° of the minimum. This night effect of drawing the needle westward (3004.) proceeds slowly until 15^h or 16^h, being assisted by the rising temperature on the east urging the end still more rapidly west until 20^h, when having reached its maximum in that direction, it at 21^h turns back and is driven to extreme east in the sun-swing, through an amount of variation more than twice as great as that produced in July or Cape winter.

3039. I think the above is a true explanation of the reverse motion of the needle in the months of July and January, or Cape winter and summer. In winter the paramagnetic effect of cold air is on between 12^h and 19^h, remaining longer on the east side of the magnetic meridian; as it passes forward, both it and the sun region conspire at 19^h to carry the needle westward, for though they have opposite actions they are then also on opposite sides of the magnetic meridian (3005.). In the summer the cold region has much less power, occurs earlier*, soon passes over, for the summer sun is behind it, and then rather aids the sun in carrying the needle westward.

3040. Some of the other months are still more striking in summer effect. February has a swing through $8'$ from west to east between 21^h and 1^h; then from 1^h to 3^h it scarcely changes; from 3^h to 6^h it follows the sun west; from 6^h to 16^h it varies but little, showing the merest trace of east effect about 8^h; and after 16^h it passes west more and more rapidly, so that by 21^h it is at a maximum west, ready to swing back as the sun region passes over. The other and intermediate months are easily traced, and found to be beautifully consistent with the same principles of the hypothesis. As is evident, in almost every case each month partakes of the character of the preceding month in some degree, though not so much in this case of the Cape as in some others (3053.). The curves of December and January are more equal.

3041. The time of the sun-swing illustrates exceedingly well the effect of the inclined magnetic meridian (3000.). In November, December and January, the swing is from 20^h to between 1^h and 2^h. In these months the sun crosses the astronomical meridian about half an hour before he arrives at the magnetic meridian. In October, February and March, the swing is later, being from 21^h to 2^h or 3^h, for the sun then passes the magnetic meridian an hour or more later than the astronomical or time meridian. In September, April and May, the swing is still later, being from 22^h to 2^h or 3^h, and the sun is still longer than before in reaching the magnetic meridian. In June, July and August, the swing is latest, being from 23^h to 3^h, and the sun is proportionately late in arriving at the magnetic meridian. What I describe as the passage of the sun is of course true of the warm region which precedes it; but I prefer referring to the visible type rather than to the invisible reality, because it ties the considerations of time more simply together.

3042. The inclination at the Cape varies singularly in the twenty-four hours, depending, I think, upon its mean degree. It is such that the warm and cold resultants of action for the Cape will sometimes be above the line of the dip and sometimes

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[*] The minimum temperature below is three hours earlier.

below it, not only for different times of the year, but I think in some seasons, even at different times of the day. It would require much attention to unravel the whole effect. In June, July and August, when the sun and its warm region are greatly to the north of the Cape, it appears that the dip is increased as the region passes, which would give a rotation of the upper end of the needle like that at Hobarton (2909.); but in November, December, January, February, March and April, the dip diminishes at that time, and the resulting rotation of the pole is of the contrary kind, or like that at St. Helena (3057.) and Singapore (3061. 3067.).

3043. The daily variations of intensity at the Cape are remarkable. In the months October to April it is at a chief maximum at 19^h or 20^h; by noon it is reduced to a minimum as the sun passes over; gradually rises to a second maximum about 4^h or 5^h, and then, after sinking a little about 8^h or 9^h, reaches the chief maximum about 18^h or 19^h next morning. In the months from May to September the chief maximum is at 21^h or 22^h, which is followed by a minimum at 1^h or 2^h, due to the day effect. Then comes on the 5^h maximum, and after thirteen hours or more the second minimum as low almost as the former, and only three hours before the chief maximum; so that this maximum is placed between minima close on each side of it.

3044. These are exactly the months during which the upper end of the needle moves eastward in early morning up to 19^h, and that is just the hour when the minimum intensity occurs. From 18^h or 19^h to 21^h the intensity rises to a maximum, precisely as the lines of force are moving westward before the sun region, prior to their quick return east; and as they return in their quick journey so the intensity falls to a minimum again, and is at that minimum at 1^h or 2^h, just as the swing is over. Here is a very close connexion, and it is curious to see the needle end at east with minimum power at 18^h, and again also at 1^h, remembering that in that time it has swung from east to west and back to east again.

3045. *St. Helena**.—This is a station which Colonel SABINE has distinguished as of the highest interest; being near the line of least force, within the tropics, and with little magnetic inclination†. It was here also that he called attention to the striking fact, that the course of the needle is in some months in one direction, and in other months in the contrary for the same hours of the day‡. DE LA RIVE attempted to explain this fact§, but SABINE has stated that this explanation is not satisfactory¶.

3046. St. Helena being a small island in the south Atlantic ocean is removed about 1200 miles from the nearest land. The longitude is 5° 40′ west, the latitude 15° 56′ south; the mean declination 23° 30′ west, and the mean dip 22° south. Hence there are three quadrants concerned in the day action of the sun, especially when that luminary is south of the equator. The sun is south of St. Helena itself in the months of November, December, January and February, or for nearly that time; it is north of the island for the rest of the year. At one time the sun passes the astronomical meridian before it arrives at the magnetic meridian, and at another time the contrary is the case. In addition to these peculiar circumstances, St. Helena is a place of great local differences, and also its dip is so low that the sun's day effect is almost constantly to depress and lessen it.

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* See Tables, pp. 119, 120, and curves of variation, Plate II.

† Magnetical Observations, St. Helena, 1840 to 1843.

‡ Philosophical Transactions, 1847, p. 51.

§ Annales de Chimie et de Physique, March 1849, tome xxv. p. 310.

¶ Proceedings of the Royal Society, May 10, 1849, p. 821.

3047. In June and July the sun rises to St. Helena in the south-east quadrant; about an hour after it passes into the north-east quadrant, and crosses it towards the southern end, being then at mid-distance in the quadrant about one-third of the length, or nearly 60° from the southern termination. It leaves this quadrant about $1^h\ 20^m$, crossing the magnetic meridian at that time (and consequently so long *after* passing the astronomical meridian), and entering the third or north-west quadrant traverses it obliquely towards its northern extremity. In our winter, December and January, the sun also rises to St. Helena in the south-east quadrant, as before; but it now remains in it until 22^h, being for much of the time in strong places of action; it enters the north-east quadrant to the south of St. Helena, and does not remain in it two hours, being then only in the weakest part of it; it leaves it again *before* arriving at the astronomical meridian, then enters the north-west quadrant, gliding along near to its southern side, and is within two-thirds of an hour of leaving it when it sets to St. Helena.

3048. As June presents the aspect of circumstances approaching nearest to that of a station further south, as Hobarton or the Cape, so I will consider the variations for it first. The north or upper end of the needle is then nearly at its mean place at midnight or 12^h: it advances east (slowly at first) until 16^h, and then more and more rapidly up to 19^h, when it stops and goes as quickly west until about 22^h, after which it changes but little until 3^h, when it moves *west* till 5^h, and then slowly east up to 12^h, and then onwards to 16^h and 19^h, as already said. The eastening from midnight, and before I refer to the paramagnetic action of the cold, which comes up from the east as before (3003. 3025. 3037.); the rapid increase of the eastening from 16^h to 19^h is consistent with the increasing cold of the early morning, and also with the circumstance, that the sun and its representative region are then passing from the south-east into the north-east quadrant, and must be not far from the neutral line, for that is the time of quickest transit of the needle. As the sun advances into the north-east quadrant, it first stops the eastening, as at 19^h, and then converts it into westening (3014.), which goes on consistently with all former observations until 22^h; the needle is then retained a little west of its mean position until 1^h, at which time it has not yet attained coincidence with the magnetic meridian, and after this hour it is determined east a little until 3^h. This effect, from 22^h to 3^h, I consider as the sun-swing to the east; and I think, examining the globe (2996.), its small amount in declination is quite consistent with the relative positions of St. Helena and the warm region, combined with those of the active and neutral parts of the quadrants traversed during the time. From 3^h to 5^h the needle end moves westward, following the sun; and that effect harmonizes with the idea that the previous holding of the needle in an eastern position, from 22^h to 3^h, is the sun effect: then the slow eastening from 5^h to midnight and beyond, is the cold effect coming on.

3049. Colonel SABINE has shown that the months of May, June, July and August, may be classed together, so that I will not speak of each. Whilst they show the analogies they have between themselves, they also indicate the transitions to and from the other months. Let us consider September. From 7^h, through midnight on to 16^h, the needle stands nearly at the mean. From 16^h to 18^h, the upper or north end eastens through the effect of the early morning cold. That the eastening should be fully effected an hour sooner than before (3048.) is quite consistent with the principles, for the path of the sun and its diamagnetic region is far nearer to the station than before, being now about the equator. From 18^h to 22^h it sends the end westward, in conformity with all former observations, and then comes on the sun-swing from west to east, between 22^h and 24^h, and a hold at extreme east an hour longer. The shortness in time of this transit is, I think, a beautiful point. The sun is still north of St. Helena, but is now so much nearer that he passes through the *same angle* east and west, in respect to the place of observation, in less than half the time of the former sun effect in June (3041). After this the needle end travels west from 1^h to 6^h, following the sun as on other occasions; and then from 6^h to 9^h it moves a little east by the evening cold in the east, and remains near the mean position until the greater cold before sunrise (3005. 3011.) takes it more east between 16^h and 18^h of the coming day.

3050. In looking at the curves of variation (Plate II.), it will be seen that the curve for the next month, October, is remarkable for being like in general character, and yet far removed in place from that of September; and this effect appears due to the circumstance that the sun has now arrived at the latitude of St. Helena, or nearly so. According to my supposition, there has been a feeble night effect (3010.); and at midnight the needle is at the mean position and moving slowly westward, when the greater cold which precedes the sunrise coming into action on the east, counterbalances and arrests the western progress, and even draws the needle, as before, east a little for a couple of hours, till 18^h. Even the sun region is at 16^h in that quadrant (the south-east one), that if it could act on the needle it would combine with the cold in the next or north-east quadrant in setting it eastward. By 18^h both the preceding cold region and the following sun region are so far advanced in their respective quadrants that they combine to carry the needle end west as before, until 20^h, and then comes on the swing from west to east until 24^h. Why this begins sooner, lasts longer, and is above four times the extent of the September swing, appears to be that the sun region comes up upon the latitude of St. Helena, and so acts in respect of the magnetic meridian more powerfully, and also sooner and longer: also that because of the mean declination west it arrives at equidistant points from and passes over the magnetic meridian sooner; and also from the effect of an accumulative action added to it from former months (3053.).

3051. At 1 o'clock the needle begins to turn from extreme east, *i. e.* sooner than in the former months, because the magnetic meridian is sooner passed, and follows the sun until 4^h, when it stops, and then the evening or night action due to cold appearing in the east, carries the needle back eastward till 10^h, and then as it advances in the quadrant lets the needle return back again (3004.) until between 12^h and 13^h, when the latter is in its mean position. The cold region then appears to draw it westward until 16^h, when its distance increasing it releases the needle, and lets it return east until 18 o'clock, when the latter is still west of its normal position, and then the sun region rising up, helped perhaps by the cold that immediately precedes it, which is probably now over or beyond the magnetic meridian, sets it toward the west prior to the sun-swing.

3052. In December and January the sun is south of the station. This makes no difference in the general character of the curve for these months; nor should it according to the hypothesis, except in this point, that though the sun is very near to St. Helena and has the cumulative effects of the preceding months (3050. 3053.) added to its own effect at the time, still it is in weaker parts of the quadrant, and whilst in the chief segment is almost up in the corner and near the place where the two neutral planes cross each other; hence its effect ought to be less, and so it is; for the sun-swing of November and February is larger than that of December and January. The sun-swing happens in December at the same time as for October, though in the latter month it crosses the magnetic meridian after, and in the present before midday: still there is only half an hour's difference from one to the other, and the observations are perhaps not close enough to allow one to separate its peculiar effect out of an interval of four hours. Besides, accumulative causes may interfere: the places of the December curve are altogether a little more west than those for October.

3053. The *cumulative* effect of preceding months is very important and well-shown at St. Helena (3050.). Thus, taking the September curve and comparing it with that for October or the following month, we have a great difference of a certain kind; then again comparing September with the month in which the sun is returning from the southern tropic instead of proceeding to it, and has arrived at the same position as it had in October, another striking difference appears. March is the nearest month for the second comparison. Up to 20^h its curve changes like the October curve, but the upper end of the needle is all the time about half a minute east of its place in October. At 20^h the needle in October begins to swing from west, and reaches extreme east at 24^h: in March it westens until 21^h, then returns and reaches extreme east at 1^h; so that the swing is an hour later, and during that time the end is from half a minute (of space) to a minute more west than in October. This difference I believe to be due to the cumulative effect of the months between October and March, during which time the heat has been diminishing in the northern hemisphere, and increasing in the south. Similar results in other months make it probable that the effect of the atmosphere, though induced by the sun, lags behind the luminary, considered as in his astronomical position all the year round; and that therefore in advancing to and receding from a tropic, he seems to do less in the first instance and more in the second than is due to his place for the time.

3054. But where circumstances are apparently equal, a difference also arises. Thus from March to April in one direction, and from September to October in the other, might be expected to be alike, except for a little of the lagging effect (3053.), which would appear on both sides: nevertheless March and April are in SABINE's curves *between* September and October, and near together, whilst the other two are far apart. This effect I refer to the different conditions of the two hemispheres as regards heat (DOVE). From September to October the sun is passing from a hemisphere having a mean temperature in summer 17°·4 above that of the other hemisphere for its winter; but in March and April it is departing from a hemisphere having a mean summer temperature of only 10°·7 above that of the other hemisphere for its winter (2949.); and these respective differences must tend to separate September and October, and bring together March and April, as is seen to be the case by the curve charts, Plate II.

3055. I need not go further into the declination variation of St. Helena: the lines for the other months are subject to the observations already made. Colonel SABINE's important query of the cause of difference in direction for different months (3045.), appears to me at present to be answered for this station, as well as for the other stations, in very various latitudes where it makes its appearance (3016. 3022. 3039.).

3056. The *dip* at St. Helena is a daily variation very simple in character, being a maximum at 7^h and a minimum at 22^h and 23^h, with only one progression. It proceeds to its minimum therefore in the middle of the sun-swing, *i. e.* the upper end of the needle proceeds to west, and descends from 16^h to 19^h or 20^h, during which time therefore the dip is decreasing; then it returns east until it reaches the neutral position, the dip decreasing the while still more. The needle still continues to go east to complete the sun-swing, but now the dip increases; at 24^h or 1^h the needle returns (in declination) after the sun westward, but still with increasing dip; at 5^h or 6^h the westening has almost ceased, and an hour after the dip is at its maximum.

3057. So as the sun and its region pass over they diminish the dip by depressing the upper ends of the lines of force, and as they pass away the lines rise (2926. 2937.) and the dip increases. The ellipse or curve, therefore, which represents the motion of the upper end of the needle at St. Helena, as the sun comes up from the east, is above westward and downward, and back below to east; then rising to be repeated in the next twenty-four hours. This is the reverse direction to the representative ellipse for Hobarton, having like south dip in a greater degree. But that is in perfect consistency with the hypothesis; for as the region is located above in the air, it is above the angle which the dip makes with the horizon at St. Helena, and therefore ought to depress the line of force and lessen the dip. At Hobarton, the region being in the tropical parts, is within the angle formed by the line of dip with the horizon, and therefore deflects the lines of force upwards and *increases* the dip, and so the portions of ellipse at the two places, which correspond in time and direction as to declination, have contrary variations of inclination.

3058. *Singapore**.—This is a very interesting station: being in longitude 103° 53′ E., it has only 1° 16′ N. latitude, and so is close to the equator. Its declination too is only 1° 40′ E., and its inclination 12° S. It is also near the line of weakest force round the earth. The magnetic equator of the needle is almost parallel to the earth's equator, and the quadrants (2929.) are distributed with great simplicity, the magnetic and astronomical meridian nearly coinciding. In our summer the sun passes through the east and west northern quadrants during the daytime; in our winter through the east and west southern quadrants; and in certain months through all four quadrants, following nearly the neutral line of the magnetic equator.

3059. Hence if the line of force were free, *i. e.* if it had no hold in the earth (2919.), we should expect from the hypothesis little or no change in the needle, especially in the months when the sun was over the magnetic equator; but because there is dip, and the lines of force which govern the needle are to the south tied up in the earth (2929.), whilst they are free to move in the air and space toward the north, so there is variation both of the declination and inclination in a perfectly consistent manner; and keeping this in mind, I think we shall have no difficulty in tracing the monthly results according to the hypothesis.

3060. In the first place, the curves of day variation are so like those of St. Helena, month for month, that the account given of them there will suffice for the present occasion (3048.). The sun-swing occurs at the same period, and the effect, dependent, as I suppose, on the character of the two hemispheres, is produced (3054. 2949.). There are however striking differences in the latter part of the sun turn, and also in the night hours, from 5^h to 14^h. The amount of variation appears small; but this is chiefly due to the circumstance that the horizontal plane on which we read it, almost coincides with the free needle, and so the correction before referred to (3009. note) necessary to give the true value of the variation is here very small.

3061. Considering *June* first, as at St. Helena, the upper needle end moves east as before until 19^h, under the influence of the morning cold, after which it stops and is sun-driven west until 22^h, when it swings downwards and beneath to east by 3^h; then follows the sun west until 7^h; it then stops and returns, creeping more and more east because of the coming cold (3065.). In July the needle eastens a little more before 19^h; westens until 23^h, and then eastens until 4^h. The sun-swing is thus thrown an hour later than in June, which I believe to be connected with the accumulation of heat over the land (3054.), combined with the lagging effect of the sun (3053.). In August the needle end eastens until 19^h; more than in July, and most of all the months: it then westens strongly before the sun until 23^h, after which the sun-swing comes on and continues until 5^h, as if the warm region were behind the sun, perhaps even 2^h. The time of the swing is much prolonged, and not unnaturally, as the place is at the equator and therefore under the sun. In September the eastening is less, the westening is less, and the sun-swing is less. April is like September, except that the latter shows the effect of the previously warmed hemisphere (3053.).

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* See Tables, pp. 121, 122, and the curves of variation, Plate II. The data for Singapore are deduced from the recent very valuable labours of Captain Elliot.

3062. Then there are four months in the year, November, December, January and February, when the sun is south of Singapore, and altogether during the day in the southern quadrants (3058.). As the sun comes on from 16^h or 17^h, the upper part of the line of force moves westward (the lower being fixed in the earth) until 19 or 20 o'clock. The sun is at this time in the south-east quadrant, and it might be expected perhaps that the motion of the north or upper end of the needle should be to the east if there were any change at all. But there are two or three reasons, from the hypothesis, why this should not be. For that effect there should first of all be no dip; and in the next place, if there were no dip, the sun is so nearly in the neutral line of the magnetic equator, that the deflection, if any, would have been very small. On the other hand, the lines of force have dip to the south, and being therefore held in the earth; that travelling of the sun along the neutral line, which in its coming up would have sent the whole line of force west, and so caused no variation of declination, can now only send the northern parts, as they rise out of the earth and are carried on with the general system of lines, west, and so cause that western travelling of the needle which does occur. Besides this, though the sun be south of that neutral line and also of Singapore, there is reason to suppose that the middle or resultant of the warm region is north even of both (3063.), which would aid the westening of the needle just described.

3063. For if we recall to mind DOVE's results, they show that the northern hemisphere, as a whole, is warmer than the southern (2949.). Again, if we look at the meridian of Singapore, we shall find that there is far more continent on the north of it, to produce a higher temperature, than to the south; and even by the local tables of temperature below, we shall find that May, June, July and August are the hottest months for Singapore, and November, December, January and February the coldest; all tending to make us suppose that the warm region of the atmosphere is relatively north of the sun's place, and perhaps even of Singapore (3067.).

3064. At 20^h the sun-swing from west to east comes on, and continues until 2^h, after which the needle moves west, following the sun, until 10^h or 11^h when it is near the mean; it still goes on westening very slowly until 17^h, when the morning sun action takes it up and drives it more quickly west, until about 20^h, when the sun-swing east occurs. The curve in these months is very simple in its character; the night or cold effect appears to be but small, being indicated rather by a hesitation than by a distinct movement east.

3065. The easterly movement of the needle end in May, June, July and August, and the westerly movement in November, December, January and February, for the same hours, up to 19 o'clock, is in striking contrast; and I have attributed the difference to the effect of a cold region coming on from the east during the former months (3061.), which is absent in the latter months. In reference to this point, we have again to consider that the warm region is on the north of the equator (3063.), and that as the sun moves north and south it also will move with it, but still keeping north of it. Hence the two cold regions, which come up to the meridian in higher latitudes (3006.) before the sun, will not be in the same relation to Singapore, for the one on the south will be nearer to it than the one on the north, or at all events more powerful. So when the sun is near and at the southern tropic, the warm region probably passes *over* Singapore, at which time, therefore, whilst it is the nearest, the most powerful and most direct in position, the cold regions will be *least* in force at the station, and also least favourably disposed by position. But when the sun is at the northern tropic, then the power of the warm region is diminished, both by distance and direction, and the southern cold region grows up into importance by increased strength and closer vicinity, and so produces the eastening before 19^h.

3066. A striking difference in the direction of the night curves, from 5^h to 14^h, at St. Helena and Singapore may be observed. At the former place the needle end tends first east and then west, whilst at the latter it moves first west and then east. The difference is, I believe, due to the appearance of night cold action at St. Helena to a greater extent than at Singapore. Singapore shows that action in June, July and August, as just described (3065.), but only in a weak degree and at a late hour. At St. Helena, which is in latitude 16° S., the cold effect should, for the reasons given above (3065.), appear in more power, and hence the eastening at 6^h and after; and that this is the cause is indicated also in a degree by the tables of temperature; for whilst at Singapore the difference between the maximum and minimum in the twenty-four hours is only from 3° to 4°, at St. Helena it is from $4^\circ\cdot5$ to 7°, and four-fifths or even five-sixths of this depression occurs by 9 o'clock: so that four or five hours before that, there was in the east a cold region coming up and producing the eastening effect recorded in the curves.

3067. The *inclination* variation at Singapore is beautifully simple, and such as might be expected from the hypothesis; the sun or warm region, when passing the meridian, always being over the lines to depress them. It is alike in all the months, being greatest at night-time and least at midday; it is nearly the same from 8^h to 18^h; then as the sun comes up it decreases quickly until 23^h or 24^h, after which, as the sun passes away, it increases nearly as quickly until 7^h or 8^h. The amount of variation is greatest when the sun is over or to the south of Singapore. It is least in June and July, when he is near the northern tropic. In December and January, when he is near the southern tropic, it is considerably more than in June and July, which again seems to show that the warm region is chiefly north of the sun (3063.).

3068. The total force variation is simple, being a maximum from 9^h to 12^h, and a minimum at 22^h or 23^h, near noon. The greatest variation is in April and October, or at the equinoxes, and the least in December and June, when the sun is at the tropics. The force is the least towards noon, when I suppose that the air above is in the worst condition of conduction, and would cause a magnet in it to show more power. But how that may affect the curves beneath on the surface of the earth, where they are compressed together, is doubtful, and the whole matter of intensity is too uncertain and has too many bearings for me to consider it usefully here.

3069. I hope soon to give further experimental data for the purpose of illustrating and testing the view of the physical cause of the magnetic variations which I have put forth, namely, those I expect to obtain by the differential balance, and others concerning the sensible influence of oxygen in causing, under different conditions, deflection of the lines of magnetic force.

Royal Institution,
November 16, 1850.

Cape of Good Hope.—Longitude 18° 30′ East. Latitude 33° 56′ South. Declination 29° 05′ West. Inclination 53° 15′ South.

Mean Diurnal variation of the Declination in each month of the years 1841 to 1846.

Increasing numbers denote a movement of the north or upper end of the magnet towards the East.

Mean time ...	Noon. 0^h.	1^h.	2^h.	3^h.	4^h.	5^h.	6^h.	7^h.	8^h.	9^h.	10^h.	11^h.	Midn. 12^h.	13^h.	14^h.	15^h.	16^h.	17^h.	18^h.	19^h.	20^h.	21^h.	22^h.	23^h.	Daily means.
January	4′·11	5′·43	5′·50	5′·04	4′·64	4′·29	3′·96	4′·16	4′·43	4′·36	4′·27	4′·13	3′·98	3′·79	3′·56	3′·32	3′·09	2′·67	2′·01	1·15	0′·37	0′·36	1′·39	2′·93	3′·28
February......	5·51	7·48	8·21	7·86	7·06	6·11	5·74	5·83	5·90	5·82	5·74	5 69	5·78	5·73	5·55	5·50	5·38	5·27	4·90	3·36	1·26	0·00	0·82	2·96	4·93
March.........	5·34	6·74	7·29	6·93	6·17	5·48	5·32	5·33	5·42	5·39	5·28	5·40	5·34	5·52	5·59	5·54	5·52	5·39	4·95	3·22	1·04	0·02	1·26	3·44	4·66
April	4·07	5·00	4·76	4·21	3·75	3·53	3·42	3·39	3·44	3·45	3·51	3·56	3·53	3·98	3·96	4·07	4·17	4·32	4·15	3·29	1·32	0·00	0·39	0·06	3·30
May............	1·83	2·49	2·81	2·92	2·50	2·15	2 17	2·31	2·33	2·30	2·45	2·41	2·64	2·83	2·87	3·10	3·24	3·36	3·80	3·91	2·31	0·68	0·00	0·62	2·42
June	0·74	1·27	1·87	1·87	1·36	1·05	1·11	1·19	1·24	1·34	1·49	1·63	1·74	2·00	2·04	2·25	2·22	2·28	2·59	3·21	2·38	0·86	0·00	0·10	1·58
July............	0·60	1·18	1·96	2·09	1·54	1·06	1·06	1·09	1·19	1·31	1·46	1·74	2·03	2·22	2·23	2·32	2·46	2·61	3·08	3·56	2·74	1·35	0·28	0·02	1·71
August	0·62	1·52	2·50	3·23	2·93	2·22	2·27	2·34	2·46	2·56	2·49	2·64	2·77	2·91	3·01	3·32	3·45	3·63	4·35	4·98	3·65	1·74	0·36	0·00	2·71
September ...	1·58	2·64	3·22	3·27	2·94	2·57	2·64	2·73	2·75	2·76	2·82	2·84	2·91	3·05	3·06	3·19	3·22	3·36	4·33	4·10	2·43	0·84	0·00	0·49	2·65
October	4·90	5·81	5·96	5·23	4·29	3·69	3·84	4·05	4·09	4·17	4·18	4·16	4·16	4·15	3·96	3·79	3·63	3·40	2·78	1·37	0·14	0·00	1·27	3·18	3·59
November ...	5·19	6·15	6·36	5·98	5·43	4·98	5·08	5·26	5·32	5·39	5·37	5·37	5·34	5·13	4·84	4·55	4·15	3·41	2·05	0·68	0·00	0·57	2·19	3·88	4·28
December ...	4·64	5·48	5·51	5·08	4·47	4·41	4·24	4·42	4·54	4·60	4·66	4·67	4·62	4·36	4·07	3·74	3·38	2·63	1·42	0·39	0·04	0·55	2·05	3·56	3·62

Cape of Good Hope.—Mean Diurnal variation of the inclination in each month of the year, from April 1841 to June 1846.

Increasing numbers denote increasing inclination. Inclination 53° 15′ South.

Mean time ...	Noon. 0^h.	1^h.	2^h.	3^h.	4^h.	5^h.	6^h.	7^h.	8^h.	9^h.	10^h.	11^h.	Midn. 12^h.	13^h.	14^h.	15^h.	16^h.	17^h.	18^h.	19^h.	20^h.	21^h.	22^h.	23^h.	Daily means.
January	0′·03	0′·00	0′·34	0′·56	0′·72	1′·00	1′·25	1′·35	1′·46	1′·51	1′·50	1′·41	1′·37	1′·40	1′·30	1′·22	1′·18	1′·10	0′·94	0′·99	0′·97	0′·92	0′·66	0′·23	0′·98
February......	0·13	0·00	0·44	1·05	1·55	1·91	2·01	2·14	2·14	2·09	2·94	1·94	1·70	1·63	1·65	1·56	1·63	1·70	1·66	1·94	2·26	2·08	1·45	0·66	1·56
March.........	0·11	0·00	0·46	1·05	1·45	1·86	2·09	2·21	2·16	2·02	1·94	1 79	1·79	1·46	1·35	1·46	1·45	1·50	1·51	1·69	1·81	1·66	1·00	0·41	1·38
April	0·00	0·49	1·05	1·55	1·76	1·89	2·16	2·21	2·11	2 06	1·88	1·65	1·45	1·18	1·18	1·07	1·22	1·12	1·10	1·10	1·48	1·53	0·92	0 33	1·35
May	0·00	0·38	0·70	0·86	1·08	1·16	1·27	1·31	1·49	1·59	1·39	1·32	1·16	0·89	0·93	0·89	0·76	0·68	0·30	0·15	0·53	0·66	0·56	0·12	0·84
June	0·41	0·53	0·58	0·76	0·64	0·79	0·96	1·22	1·34	1·40	1·29	1·22	1·04	0·96	0·89	0·81	0·73	0·78	0·36	0·00	0·07	0·38	0·36	0·43	0·75
July	0·62	0·64	0·59	0·64	0·77	0·87	1·18	1·20	1·46	1·43	1·43	1·21	1·07	0·95	0·77	0·87	0·67	0·60	0·28	0·00	0·18	0·51	0·64	0·56	0·80
August	0·12	0·38	0·76	0·99	1·16	1·27	1·34	1·60	1·55	1·52	1·45	1·30	1·16	1·04	0·84	0·83	0 63	0·68	0·27	0·00	0·13	0·33	0·43	0·30	0·84
September ...	0·00	0·23	0·66	1·09	1·40	1·65	1·78	1·68	1·75	1·75	1·40	1·27	0·91	0·97	0·56	0·81	0·51	0·73	0·18	0·31	0·07	0·35	0·03	0·12	0·84
October	0·00	0·08	0·53	1·17	1·75	1·98	1·98	1·89	1·88	1·75	1·60	1·50	1·28	1·23	1·20	1·10	1·09	1·07	1·07	1·09	1·04	0·77	0·36	0·05	1·14
November ...	0·14	0·00	0·29	0·64	1·12	1·53	1·41	1·46	1·48	1·33	1·25	1·08	0·99	0·94	0 90	0·87	0·87	0·94	0·80	0·62	0·46	0·26	0·06	0·00	0·81
December ...	0·13	0·30	0·87	1·22	1·40	1·53	1·78	2·01	2·04	1·81	1·70	1·57	1·50	1·48	1·47	1·50	1·50	1·40	1·05	0·81	0·48	0·15	0·02	0·00	1·15
Hourly means	0·14	0·25	0·61	0·96	1·23	1·45	1·60	1·69	1·74	1·69	1·49	1·44	1·28	1·18	1·09	1·08	1·02	1·02	0·79	0·72	0·79	0·80	0·54	0·27	1·04

Cape of Good Hope.—Mean Diurnal variation of the Intensity in each month of the year, from April 1841 to June 1846.

Increasing numbers denote increasing intensity.

The numbers express the changes in parts of the whole Force. Approximate Total Intensity 7·5.

Mean time ...	Noon. 0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	Midn. 12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	Daily means.
	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
January	000	003	018	031	041	047	048	039	036	038	040	044	045	047	049	050	052	061	071	079	078	056	028	005	042
February......	000	000	020	047	069	083	076	072	068	069	071	071	074	075	078	076	077	080	092	115	127	105	062	026	068
March.........	000	007	027	052	070	079	074	069	064	064	067	066	070	068	066	068	068	068	081	103	119	094	047	011	063
April	000	017	040	058	070	071	068	065	060	059	059	060	060	059	060	063	061	060	065	083	102	093	059	021	059
May	003	000	008	019	036	038	035	028	025	023	021	021	022	020	020	019	019	018	013	026	056	063	050	020	025
June	008	000	003	015	029	030	026	021	017	014	017	010	010	007	009	007	010	008	004	003	030	041	039	017	015
July...........	009	004	005	016	032	033	026	023	018	013	010	007	007	007	008	009	008	007	000	005	027	043	041	023	016
August	028	013	007	010	028	035	029	024	019	016	017	016	016	016	017	013	013	009	000	009	044	061	064	044	023
September ...	007	000	005	015	023	028	021	017	013	012	013	012	019	015	020	014	019	008	005	018	051	057	050	023	019
October	000	009	033	057	070	064	053	047	045	047	047	049	051	055	056	056	056	060	073	088	084	060	025	005	050
November ...	000	005	021	038	049	057	048	044	043	044	044	047	050	053	056	057	052	074	090	096	082	054	022	007	047
December ...	000	003	015	029	037	035	034	030	027	026	028	031	035	036	038	042	047	060	074	076	066	042	013	000	034
Hourly means	005	005	017	032	046	050	045	040	036	035	036	036	038	038	040	040	040	043	047	058	072	064	042	017	461

Cape of Good Hope.—Mean Temperature of the Air from April 1841 to June 1846 inclusive. FAHRENHEIT'S scale.

Mean time ...	Noon. 0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	Midn. 12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	Daily means.
January	73°·16	73°·30	73°·03	72°·43	71°·52	70°·30	67°·94	66°·11	65°·45	65°·01	64°·51	64°·10	63°·77	63°·54	63°·32	63°·06	62°·85	63°·18	65°·20	67°·24	68°·78	70°·05	71°·46	72°·59	67°·58
February......	74·04	74·07	73·63	72·85	71·74	70·36	68·20	66·69	66·13	65·75	65·34	64·93	64·54	64·23	64·00	63·60	63·41	63·12	64·46	66·33	67·94	69·72	71·62	73·10	67·91
March.........	71·74	72·40	72·19	71·40	69·96	68·07	65·98	64·98	64·38	63·69	63·20	62·85	62·37	62·06	61·69	61·44	61·15	60·97	61·31	63·03	65·39	67·48	69·50	71·00	65·76
April	68·39	68·94	68·90	68·06	66·56	64·22	62·69	62·13	61·54	60·98	60·46	59·87	59·53	59·27	59·00	58·80	58·40	58·28	58·17	59·49	61·82	64·14	65·95	67·35	62·62
May...........	62·32	62·55	62·43	61·74	60·49	58·99	58·08	57·41	56·81	56·39	55·85	55·48	55·37	55·21	55·05	54·81	54·59	54·32	54·04	54·44	56·42	58·48	60·09	61·29	57·61
June	58·45	58·79	58·78	58·32	57·01	55·58	54·79	54·25	53·71	53·25	52·77	52·32	52·16	51·86	51·69	51·53	51·21	50·95	50·80	50·83	52·20	54·42	56·17	57·42	54·14
July	59·15	59·66	59·65	59·21	57·77	56·13	55·15	54·47	53·83	53·34	52·86	52·37	52·08	51·72	51·42	51·19	50·96	50·83	50·51	50·88	52·67	54·94	56·87	58·28	54·41
August	58·86	59·23	59·07	58·61	57·61	55·91	55·01	54·35	53·91	53·60	53·17	52·91	52·71	52·31	52·07	51·87	51·54	51·19	51·15	51·88	53·19	55·57	57·05	58·30	54·63
September ...	61·60	61·79	61·68	60·87	59·65	58·02	56·78	56·09	55·62	55·22	54·58	54·47	54·36	53·95	53·64	53·31	53·10	53·20	53·13	54·94	56·90	58·61	59·94	60·94	56·77
October	65·48	65·71	65·46	64·66	63·38	61·56	59·51	58·68	58·05	57·51	57·14	56·74	56·70	56·33	56·11	55·88	55·64	55·63	57·14	59·08	61·00	62·75	64·07	65·04	59·97
November ...	68·00	68·03	67·63	66·98	66·19	64·82	62·49	61·12	60·38	59·99	59·52	59·12	58·82	58·43	58·00	57·69	57·48	58·14	60·55	62·50	63·96	65·27	66·50	67·50	62·46
December ...	71·02	71·23	70·84	70·21	69·63	68·23	65·69	63·94	63·19	62·64	62·07	61·59	61·18	60·82	60·49	60·17	59·91	60·83	63·41	65·80	67·17	68·42	69·62	70·42	65·35

St. Helena.—Longitude 5° 40′ West. Latitude 15° 56′ South. Declination 23° 36′ West. Inclination 21° 40′ South.

Mean Diurnal variation of the Declination for the years 1841 to 1845 inclusive.

Increasing numbers denote increasing eastening of the north or upper end of the needle. Mean Declination 23° 36′·6 West.

Mean time ...	Noon. 0^{h}.	1^{h}.	2^{h}.	3^{h}.	4^{h}.	5^{h}.	6^{h}	7^{h}.	8^{h}.	9^{h}.	10^{h}.	11^{h}.	Midn. 12^{h}.	13^{h}.	14^{h}.	15^{h}.	16^{h}.	17^{h}.	18^{h}.	19^{h}.	20^{h}.	21^{h}.	22^{h}.	23^{h}.	Daily means.
January	3′·72	3′·19	2′·41	2′·03	2′·09	1′·84	1′·92	2′·41	2′·80	2′·90	2′·86	2′·81	2′·63	2′·43	2′·23	2′·01	1′·73	1′·68	1′·50	0′·59	0′·00	0′·57	1′·75	3′·15	2′·13
February......	4·53	4·51	4·11	3·39	2·80	2·55	2·61	3·02	3·21	3·35	3·48	3·52	3·42	3·22	3·12	2·98	2·83	2·75	2·64	1·14	0·00	0·31	1·52	3·34	2·85
March.........	3·76	4·11	3·48	2·57	2·15	2·20	2·48	2·64	2·69	2·68	2·85	2·84	2·80	2·77	2·68	2·70	2·69	2·70	2·96	1·90	0·26	0·00	1·13	2·72	2·49
April	3·28	2·48	1·65	1·27	1·03	1·01	1·23	1·50	1·56	1·60	1·71	1·81	1·96	1·92	1·92	2·00	2·16	2·22	2·47	2·15	0·62	0·00	0·82	2·57	1·70
May	0·71	0·44	0·57	0·71	0·55	0·21	0·25	0·48	0·56	0·72	0·78	0·90	1·02	1·09	1·11	1·18	1·32	1·57	2·04	2·58	1·50	0·32	0·00	0·49	0·88
June	0·71	0·73	0·88	0·94	0·44	0·00	0·10	0·39	0·56	0·73	0·90	1·06	1·17	1·22	1·25	1·29	1·40	1·66	2·16	3·31	2·69	1·39	0·75	0·69	1·10
July	0·82	0·71	0·78	0·84	0·48	0·02	0·00	0·22	0·46	0·64	0·84	0·98	1·08	1·14	1·14	1·24	1·31	1·46	2·02	3·11	2·58	1·31	0·63	0·67	1·02
August	0·11	0·00	0·40	0·86	0·82	0·42	0·25	0·52	0 68	0·78	0·88	1·02	1·02	1·02	1·04	1·18	1·27	1·61	2·37	3·43	2·52	1·19	0·36	0·05	0·99
September ...	0·89	0·85	0·65	0·44	0·35	0·28	0·28	0·53	0·62	0·67	0·79	0·78	0·75	0·64	0·61	0·65	0·70	0·95	2·12	1·89	0·85	0·17	0·00	0·43	0·70
October	4·41	4·35	3·43	2·06	1·23	1·32	1·80	2·04	2·21	2·34	2·45	2·43	2·23	2·00	1·92	1·81	1·72	1·74	1·99	0·49	0·00	0·72	2·08	3·61	2·10
November ...	3·97	3·82	3·31	2·52	1·85	1·85	2·29	2·77	2·99	3·13	3·21	3·13	2·96	2·68	2·46	2·22	1·97	1·80	1·53	0·21	0·00	1·03	2·22	3·41	2·39
December ...	3·65	3·48	2·70	1·94	1·66	1·85	2·15	2·58	2·93	3·12	3·20	3·13	2·89	2·64	2·40	2·17	1·93	1·73	1·38	0·32	0·00	0·86	2·09	3·32	2·25

St. Helena.—Mean Diurnal variation of the Inclination in each month, from January 1841 to December 1845.

Increasing numbers denote increasing inclination. Mean Inclination 21° 40′ South.

Mean time ...	Noon. 0^{h}.	1^{h}.	2^{h}.	3^{h}.	4^{h}.	5^{h}.	6^{h}.	7^{h}.	8^{h}.	9^{h}.	10^{h}.	11^{h}.	Midn. 12^{h}.	13^{h}.	14^{h}.	15^{h}.	16^{h}.	17^{h}.	18^{h}.	19^{h}.	20^{h}.	21^{h}.	22^{h}.	23^{h}.	Daily means.
January	0′·14	0′·46	1′·07	1′·49	2′·18	2′·53	2′·77	2′·91	2′·87	2′·83	2′·77	2′·63	2′·40	2′·23	1′·99	1′·85	1′·80	1′·77	1′·65	1′·37	0′·88	0′·53	0′·00	0′·02	1′·71
February......	0·23	0·61	1·33	2·00	2·39	2·78	3·01	3·15	3·12	2·98	2·86	2·73	2·61	2·46	2·44	2·21	2·15	2·00	2·04	1·82	1·40	0·94	0·10	0·00	1·97
March.........	0·11	0·56	1·33	1·86	2·21	2·47	2·80	2·97	2·99	2·89	2·89	2·67	2·46	2·37	2·26	2·12	1·99	2·01	1·84	1 53	1·06	0·43	0·00	0·10	1·83
April	0·45	0·89	1·54	2·14	2·53	2·83	3·05	3·17	3·26	2·88	2·97	2·63	2·41	2·18	2·15	2·08	1·88	1·77	1·47	1·30	0·94	0·43	0·27	0·00	1·88
May............	0·20	0·74	1·16	1·62	1·90	2·10	2·22	2·36	2·28	2·21	2·12	1·99	1·77	1·69	1·56	1·33	1·21	1·16	1·18	1·09	0·81	0·36	0·00	0·03	1·38
June	0·18	0·56	1·04	1·58	1·65	1·91	2·21	2·26	2·24	2·12	2·02	1·98	2·06	1·77	1·68	1·54	1·46	1·36	1·22	0·98	0·80	0·43	0·09	0·00	1·38
July	0·30	0·60	1·06	1·44	1·82	2·01	2·42	2·47	2·40	2·35	2·21	2·04	1·80	1·58	1·52	1·30	1·25	1·08	1·00	0·84	0·53	0·27	0·00	0·03	1·35
August	0·25	0·72	1·21	1·61	1·94	2·16	2·35	2·40	2·39	2·19	2·12	1·98	1·80	1·69	1·58	1·40	1·33	1·25	1·13	1·07	0·79	0·54	0·19	0·00	1·42
September ...	0·18	0·70	1·29	1·72	2·02	2·19	2·40	2·40	2·32	2·13	2·01	1·99	1·80	1·68	1·47	1·50	1·51	1·44	1·40	1·27	0·92	0·60	0·36	0·00	1·47
October	0·24	0·74	1·36	1·90	2·34	2·56	2·55	2·88	2·65	2·56	2·46	2·28	2·09	2·04	1·89	1·80	1·70	1·69	1·63	1·31	0·88	0·37	0·00	0 02	1·66
November ...	0·08	0·27	0·74	1·19	1·63	2·00	2·35	2·45	2·38	2·30	2·18	2·07	1·96	1·83	1·71	1·59	1 66	1·48	1·35	0·92	0·55	0·23	0·00	0·10	1·38
December ...	0·26	0·73	1·06	1·59	2·08	2·41	2·69	2·78	2·61	2·45	2·39	2·15	2·01	1·80	1·72	1·56	1·48	1·38	1·26	0·85	0·40	0·10	0·00	0·07	1·49
Hourly means	0·22	0·63	1·18	1·68	2·06	2·33	2·57	2·68	2·63	2·49	2·42	2·26	2·10	1·94	1·83	1·69	1·62	1·53	1·43	1·20	0·83	0·44	0·08	0·03	1·58

St. Helena.—Mean Diurnal variation of the Total Intensity in each month, from January 1841 to December 1845.

Increasing numbers denote increasing intensity.

Mean time ...	Noon. 0^h.	1^h.	2^h.	3^h.	4^h.	5^h.	6^h.	7^h.	8^h.	9^h.	10^h.	11^h.	Midn. 12^h.	13^h.	14^h.	15^h.	16^h.	17^h.	18^h.	19^h.	20^h.	21^h.	22^h.	23^h.	Daily means.
	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
January	130	129	116	098	081	063	046	027	016	004	000	001	001	008	015	015	019	019	024	040	055	080	109	124	051
February......	117	109	092	077	063	050	029	014	007	001	002	003	004	002	000	002	002	003	009	023	046	070	095	114	039
March	153	147	124	096	070	055	032	020	010	000	006	004	001	016	014	018	018	021	026	040	068	102	132	149	055
April	162	150	122	088	068	042	021	010	005	001	004	000	007	014	015	016	025	024	024	031	054	090	102	150	051
May............	163	142	115	087	065	049	036	023	016	011	004	000	008	008	011	018	019	019	025	034	048	095	132	159	054
June	141	128	101	064	063	047	028	015	006	004	001	000	002	003	004	004	004	009	013	022	042	075	110	137	043
July............	126	117	095	073	051	042	027	015	011	002	002	000	003	005	006	011	015	018	019	024	038	068	097	116	041
August	139	126	103	077	053	038	026	013	004	001	000	000	002	005	009	015	015	016	016	018	037	068	103	131	039
September ...	143	131	105	077	056	037	026	013	004	000	003	007	011	014	018	024	022	024	023	022	038	069	101	134	046
October	135	123	105	088	070	051	030	015	007	001	010	005	011	013	019	020	019	020	017	032	058	093	123	135	050
November ...	112	111	101	090	076	055	029	018	007	000	002	009	011	011	016	017	017	017	026	048	071	087	105	112	048
December ...	116	110	105	089	071	051	027	011	004	000	000	003	003	006	008	010	011	012	024	046	064	086	107	117	045
Hourly means	136	127	107	084	066	048	030	016	008	002	002	003	006	009	011	014	015	017	021	032	052	082	110	132	047

St. Helena.—Mean Temperature of the Air from 1841 to 1845 inclusive.

Mean time ...	Noon. 0^h.	1^h.	2^h.	3^h.	4^h.	5^h.	6^h.	7^h.	8^h.	9^h.	10^h.	11^h.	Midn. 12^h.	13^h.	14^h.	15^h.	16^h.	17^h.	18^h.	19^h.	20^h.	21^h.	22^h.	23^h.	Daily means.
January	67°·68	68°·05	67°·93	67°·79	67°·30	66°·04	64°·58	63°·39	62°·93	62°·62	62°·42	62°·27	62°·06	61°·88	61°·66	61°·60	61°·49	61°·39	61°·37	61°·84	62°·79	64°·09	65°·38	66°·55	63°·98
February......	69·14	69·61	69·85	69·59	68·95	67·89	66·59	65·43	64·91	64·66	64·46	64·32	64·13	63·96	63·78	63·59	63·51	63·44	63·42	63·62	64·43	65·72	67·08	68·24	65·87
March	69·13	69·57	69·89	69·71	69·10	68·10	66·86	65·84	65·47	65·15	65·00	64·83	64·65	64·50	64·31	64·17	64·15	64·03	64·05	64·29	65·08	66·39	67·35	68·38	66·24
April	68·54	68·89	68·98	68·64	67·99	66·98	65·84	65·15	64·84	64·61	64·45	64·29	64·11	64·02	63·88	63·77	63·66	63·51	63·49	63·69	64·50	65·70	66·74	67·86	65·60
May	65·76	66·01	66·09	65·84	65·17	64·11	63·56	63·32	62·73	62·13	62·03	61·88	61·67	61·57	61·40	61·24	61·19	61·19	61·04	61·06	62·01	63·22	64·11	65·22	63·05
June	62·40	62·76	62·73	62·39	61·83	60·98	60·14	59·68	59·49	59·34	59·20	59·11	59·00	58·86	58·74	58·61	58·56	58·53	58·47	58·52	59·13	60·16	60·98	61·80	60·07
July............	60·37	60·83	60·77	60·51	59·87	58·98	58·14	57·70	57·48	57·25	57·13	56·91	56·81	56·72	56·60	56·51	56·43	56·36	56·31	56·38	57·07	58·09	58·90	59·69	57·99
August	59·68	59·99	60·12	59·72	59·11	58·11	57·23	56·83	56·60	56·45	56·32	56·20	56·10	55·98	55·76	55·68	55·53	55·50	55·39	55·56	56·20	57·22	58·07	58·96	57·17
September ...	59·89	60·26	60·18	59·77	59·11	58·03	57·05	56·56	56·35	56·21	56·04	55·91	55·82	55·67	55·51	55·37	55·29	55·21	55·21	55·44	56·12	57·18	58·31	59·14	57·07
October	61·50	61·98	61·91	61·31	60·46	59·31	58·18	57·57	57·64	57·12	56·99	56·84	56·64	56·48	56·30	56·18	56·11	56·01	56·06	56·50	57·38	58·61	59·71	60·73	58·23
November ...	63·44	63·88	63·97	63·52	62·63	61·32	59·94	59·11	58·76	58·57	58·41	58·24	58·08	57·90	57·71	57·62	57·55	57·43	57·53	58·03	58·94	60·20	61·35	62·35	59·84
December ...	65·19	65·81	65·87	65·72	64·88	63·62	62·17	61·10	60·70	60·46	60·27	60·12	59·95	59·75	59·57	59·47	59·34	59·31	59·39	59·77	60·69	61·97	63·03	64·19	61·77

Singapore.—Latitude 1° 16′ North. Longitude 103° 53′ East. Declination 1° 40′ East (Approx.). Inclination 12° South (Approx.).

Mean Hourly oscillation of the Magnetic Declination for each month of the years 1843, 1844 and 1845.

Increasing numbers denote a movement of the north or upper end of the magnet towards the East.

Mean time ...	Noon. 0¼h.	1¼h.	2¼h.	3¼h.	4¼h.	5¼h.	6¼h.	7¼h.	8¼h.	9¼h.	10¼h.	11¼h.	Midn. 12¼h.	13¼h.	14¼h.	15¼h.	16¼h.	17¼h.	18¼h.	19¼h.	20¼h.	21¼h.	22¼h.	23¼h.	Daily means.
January	2′·04	2′·52	2′·79	2′·72	2′·52	2′·24	2′·11	2′·18	2′·04	1′·97	1′·84	1′·70	1′·63	1′·63	1′·50	1′·43	1′·29	1′·02	0′·61	0′·00	0′·00	0′·41	0′·82	1′·22	1′·59
February......	2·31	2·92	3·13	3·06	2·79	2·52	2·31	2·31	2·18	2·04	1·90	1·90	1·97	1·90	1·90	1·90	1·84	1·70	1·29	0·54	0·00	0·00	0·34	1·43	1·84
March.........	1·29	1·43	1·63	1·77	1·63	1·43	1·29	1·09	0·95	0·88	0·82	0·82	0·88	0·88	0·88	0·82	0·82	0·82	0·82	0·48	0·00	0·07	0·54	1·02	0·96
April	0·34	0·61	0·75	1·02	1·16	1·16	0 95	0·82	0·61	0·54	0·61	0 68	0·82	0·95	0·95	0·95	0·88	0·82	1·16	0·95	0·34	0·00	0·20	0·41	0·70
May...........	0·07	0·48	0 82	1·16	1·36	0·95	1·02	0·88	0·75	0·68	0·75	0·82	1·09	1·16	1·29	1·36	1·36	1·43	2·11	2·24	1·43	0·68	0·27	0·00	0·75
June	0·20	0·41	0·54	0·61	0·54	0·34	0·14	0·00	0·00	0·00	0·07	0·20	0·41	0·54	0·61	0·68	0·68	0·82	1·36	1·56	0·82	0·41	0·00	0·14	0·46
July...........	0 07	0·41	0·61	0·88	1·02	0·88	0·48	0·34	0·27	0·20	0·27	0·34	0·54	0·68	0·82	0·75	0·82	1·16	1·63	1·97	1·29	0·54	0·14	0·00	0·67
August	0·20	0·68	1·02	1·56	1·63	1·84	1·43	1·29	1·09	1·02	1·02	1·16	1·22	1·36	1·43	1·50	1·50	1·70	2·52	2·79	1·77	0·75	0·14	0·00	1·27
September ...	0·48	0·88	1·36	1·63	1·63	1·56	1·50	1·29	1·16	1·09	1·02	1·09	1·16	1·22	1·29	1·29	1·36	1·43	1·97	1·77	0·75	0·20	0·00	0·20	1·14
October	1·90	2·31	2·31	2·18	1·97	1·77	1·77	1·63	1·50	1·36	1·29	1·29	1·43	1·36	1·36	1·29	1·22	1·09	1·16	0·54	0·14	0·00	0·27	1·02	1·33
November ...	2·45	2·92	2·99	2·86	2·45	2·11	1·97	1·84	1·70	1·56	1·36	1·36	1·43	1·43	1·36	1·29	1·16	1·02	0·48	0·00	0·00	0·27	0·82	1·63	1·51
December ...	2·52	2·99	2·99	2·99	2·86	2·45	2·18	2·04	1·97	1·84	1·70	1·63	1·56	1·56	1·56	1·50	1·43	1·16	0·61	0·00	0·00	0·41	1·02	1·77	1·70

Singapore.—Mean Diurnal variation of the Inclination in the several months during the years 1843, 1844 and 1845.

Increasing numbers denote increasing inclination. Approximate inclination 12° South.

Mean time ...	Noon. 0¼h.	1¼h.	2¼h.	3¼h.	4¼h.	5¼h.	6¼h.	7¼h.	8¼h.	9¼h.	10¼h.	11¼h.	Midn. 12¼h.	13¼h.	14¼h.	15¼h.	16¼h.	17¼h.	18¼h.	19¼h.	20¼h.	21¼h.	22¼h.	23¼h.	Daily means.
January	0′·00	0′·43	0′·98	1′·28	1′·90	2′·07	2′·38	2′·57	2′·62	2′·71	2′·76	2′·76	2′·66	2′·71	2′·71	2′·72	2′·72	2′·72	2′·73	2′·52	1′·97	1′·09	0′·32	0′·02	1′·97
February......	0·04	0·64	1·24	1·75	2·00	2·21	2·56	2·82	2·94	3·02	3·10	3·07	3·08	3·03	2·98	2·99	2·97	2·97	3·03	2·88	2·35	1·21	0·40	0·00	2·22
March.........	0·06	0·29	0·75	1·36	1·75	1·88	2·22	2·55	2·65	2·70	2·74	2·72	2·72	2·67	2·71	2·72	2·72	2·75	2·75	2·54	1·84	0·75	0·11	0·00	1·91
April	0·28	0·82	1·54	2·09	2·47	2·71	3·04	3·00	3·27	3·36	3·41	3·49	3·43	3·40	3·33	3·29	3·29	3·27	3·15	2·92	2·18	1·15	0·28	0·00	2·46
May...........	0·00	0·32	0·80	1·17	1·62	1·96	2·29	2·34	2·42	2·43	2·42	2·20	2·38	2 40	2·42	2·46	2·52	2·51	2·25	1·87	1·25	0·49	0·03	0·00	1·69
June	0·04	0·20	0·57	0·98	1·44	1·50	2·20	2·25	2·19	2·16	2·10	2·07	2·15	2·21	2·15	2·20	2·21	2·29	2·02	1·71	1·25	0·69	0·22	0·00	1·53
July...........	0·00	0·15	0·45	0·89	1·34	1·76	2·10	2·16	2·19	2·20	2·20	2·07	2·18	2·19	2·19	2·21	2·21	2·27	2·02	1·74	1·28	0·69	0·27	0·05	1·53
August	0·12	0·34	0·69	1·01	1·35	1·68	1·99	2·32	2·21	2·27	2·26	2·28	2·26	2·20	2·18	2·22	2·21	2·22	1 93	1·68	1·30	0·62	0·14	0·00	1·56
September ...	0·41	1·00	1·60	1·94	2·11	2·32	2·58	2·69	2·78	2·82	2·85	2·84	2·85	2·79	2·74	2·75	2·75	2·79	2·66	2·39	1·66	0·79	0·15	0·00	2·09
October	0·38	1·17	1·94	2·38	2·48	2·59	2·86	3·07	3·23	3·29	3·34	3·23	3·33	3·23	3·22	3·20	3·24	3·20	3·25	2·96	2·18	1·14	0·21	0·00	2·46
November ...	0·16	0·63	1·37	1·96	2·32	2·68	2·88	2·87	3·02	3·08	3·07	3 06	3·06	3·03	3·02	2·95	3·01	3·00	3·15	2·80	2·01	1·04	0·17	0·00	2·26
December ...	0·09	0·54	1·13	1·62	1·92	2·26	2·53	2·66	2·85	2·86	2·85	2·86	2·76	2·76	2·72	2·69	2·65	2·69	2·44	2 38	1·81	1·08	0·34	0·00	2·02
Hourly means	0·13	0·54	1·09	1·54	1·89	2·14	2·47	2·61	2·70	2·74	2·76	2·72	2·74	2·72	2·70	2·70	2·71	2·72	2·62	2·37	1·76	0 89	0·22	0·01	1·98

Singapore.—Mean Diurnal variation of the Total Intensity in the several months during the years 1843, 1844, 1845.

Increasing numbers indicate increase of total intensity.

The numbers express the changes in parts of the whole force. Approximate total intensity 8·21.

Mean time ...	Noon. $0\frac{1}{4}^{\mathrm{h}}$.	$1\frac{1}{4}^{\mathrm{h}}$.	$2\frac{1}{4}^{\mathrm{h}}$.	$3\frac{1}{4}^{\mathrm{h}}$.	$4\frac{1}{4}^{\mathrm{h}}$.	$5\frac{1}{4}^{\mathrm{h}}$.	$6\frac{1}{4}^{\mathrm{h}}$.	$7\frac{1}{4}^{\mathrm{h}}$.	$8\frac{1}{4}^{\mathrm{h}}$.	$9\frac{1}{4}^{\mathrm{h}}$.	$10\frac{1}{4}^{\mathrm{h}}$.	$11\frac{1}{4}^{\mathrm{h}}$.	Midn. $12\frac{1}{4}^{\mathrm{h}}$.	$13\frac{1}{4}^{\mathrm{h}}$.	$14\frac{1}{4}^{\mathrm{h}}$.	$15\frac{1}{4}^{\mathrm{h}}$.	$16\frac{1}{4}^{\mathrm{h}}$.	$17\frac{1}{4}^{\mathrm{h}}$.	$18\frac{1}{4}^{\mathrm{h}}$.	$19\frac{1}{4}^{\mathrm{h}}$.	$20\frac{1}{4}^{\mathrm{h}}$.	$21\frac{1}{4}^{\mathrm{h}}$.	$22\frac{1}{4}^{\mathrm{h}}$.	$23\frac{1}{4}^{\mathrm{h}}$.	Daily means.
	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
January	086	066	047	030	028	021	015	009	009	003	002	000	007	002	008	007	010	012	022	033	054	074	099	100	031
February......	099	080	061	042	027	024	013	008	004	000	000	002	000	001	005	005	009	011	014	025	049	082	103	110	032
March.........	114	085	055	035	026	020	013	007	003	001	000	002	005	008	007	009	011	012	012	027	057	087	112	122	035
April	122	094	065	040	029	020	016	011	005	003	005	002	000	004	009	011	013	015	020	043	076	110	139	137	041
May...........	104	081	060	036	020	013	014	011	010	006	006	000	004	006	006	006	008	012	025	044	073	097	114	118	036
June	096	075	051	026	011	042	004	004	001	000	000	000	001	001	003	004	004	008	020	038	062	085	102	105	031
July	100	081	056	033	019	013	007	007	004	004	002	000	002	004	006	004	010	015	026	044	070	091	105	110	034
August	101	081	055	033	016	009	010	005	006	000	002	002	004	010	011	011	016	018	028	046	077	096	115	114	036
September ...	093	065	037	029	018	009	009	008	002	001	000	003	003	008	014	018	019	017	023	045	079	104	117	115	035
October	102	073	050	036	029	024	013	007	003	000	000	001	006	011	011	016	019	017	020	037	070	101	117	121	037
November ...	080	063	044	030	021	015	009	003	001	000	001	000	002	006	007	013	012	013	017	034	059	082	098	095	029
December ...	077	061	044	031	026	021	012	004	000	000	001	002	003	006	009	013	014	014	019	035	056	078	095	091	030
Hourly means	098	075	052	033	022	019	011	007	004	002	002	001	003	006	008	010	012	014	021	038	065	091	110	112	034

Singapore.—Mean Temperature of the Air observed on the Standard Thermometer inside the Observatory, during the years 1841, 1842 and 1843.

Mean time ...	Noon. $0\frac{1}{4}^{\mathrm{h}}$.	$1\frac{1}{4}^{\mathrm{h}}$.	$2\frac{1}{4}^{\mathrm{h}}$.	$3\frac{1}{4}^{\mathrm{h}}$.	$4\frac{1}{4}^{\mathrm{h}}$.	$5\frac{1}{4}^{\mathrm{h}}$.	$6\frac{1}{4}^{\mathrm{h}}$.	$7\frac{1}{4}^{\mathrm{h}}$.	$8\frac{1}{4}^{\mathrm{h}}$.	$9\frac{1}{4}^{\mathrm{h}}$.	$10\frac{1}{4}^{\mathrm{h}}$.	$11\frac{1}{4}^{\mathrm{h}}$.	Midn. $12\frac{1}{4}^{\mathrm{h}}$.	$13\frac{1}{4}^{\mathrm{h}}$.	$14\frac{1}{4}^{\mathrm{h}}$.	$15\frac{1}{4}^{\mathrm{h}}$.	$16\frac{1}{4}^{\mathrm{h}}$.	$17\frac{1}{4}^{\mathrm{h}}$.	$18\frac{1}{4}^{\mathrm{h}}$.	$19\frac{1}{4}^{\mathrm{h}}$.	$20\frac{1}{4}^{\mathrm{h}}$.	$21\frac{1}{4}^{\mathrm{h}}$.	$22\frac{1}{4}^{\mathrm{h}}$.	$23\frac{1}{4}^{\mathrm{h}}$.	Daily means.
January	79°·7	79°·5	80°·0	79°·5	79°·7	79°·1	79°·0	78°·4	78°·5	78°·0	78°·1	77°·5	77°·9	77°·3	77°·6	76°·9	77°·4	76°·5	77°·0	76°·3	77°·3	77°·4	78°·6	78°·8	78°·2
February......	80·7	81·6	81·2	82·1	81·2	82·1	80·2	80·6	79·7	80·2	79·2	79·6	78·6	79·0	78·3	78·6	78·2	78·2	77·7	78·2	78·0	79·4	79·6	81·8	79·8
March.........	81·4	82·1	81·7	82·3	81·6	82·0	80·9	81·5	80·5	81·2	80·1	81·0	79·9	80·6	79·4	80·3	79·1	79·9	78·7	79·8	79·4	80·6	80·6	81·5	80·7
April	81·8	81·8	82·1	81·8	81·9	81·6	81·4	81·2	81·0	80·9	80·7	80·2	80·3	80·3	79·9	80·0	79·5	79·6	79·2	79·8	79·9	80·6	81·1	81·4	80·8
May...........	82·5	......	82·7	......	82·5	......	82·1	......	81·8	......	81·4	......	80·9	......	80·5	......	80·3	......	79·9	......	80·9	......	81·8	......	81·4
June	82·5	82·9	82·7	83·1	82·5	82·7	82·2	82·0	81·7	81·6	81·4	81·4	81·2	81·2	80·7	80·7	80·3	80·2	80·1	80·4	81·0	81·7	81·8	82·6	81·6
July...........	82·4	83·0	82·8	83·1	82·7	82·7	82·2	82·1	81·8	81·9	81·5	81·5	81·1	81·2	80·7	80·9	80·3	80·6	80·8	80·8	80·8	81·9	81·9	82·6	81·7
August	81·7	81·9	81·9	81·9	81·8	81·8	81·4	81·3	81·0	81·2	80·8	80·8	80·4	80·3	80·1	80·1	79·8	79·8	79·5	79·8	80·2	80·8	81·2	81·6	80·9
September ...	82·1	82·6	82·4	82·3	82·2	82·1	81·7	81·6	81·5	81·2	81·0	80·8	80·5	80·3	80·1	80·0	79·7	79·7	79·4	79·4	80·3	80·9	81·4	81·8	81·0
October	81·5	81·3	81·7	81·4	81·7	81·2	81·2	80·6	80·7	80·2	80·1	79·8	79·6	79·8	79·4	79·3	79·0	79·3	78·7	79·2	79·5	80·0	80·7	80·9	80·3
November ...	81·1	81·0	81·3	80·8	81·0	80·6	80·4	80·1	80·1	79·7	79·7	79·6	79·3	79·1	78·9	78·7	78·6	78·5	78·4	78·5	79·2	79·6	80·2	80·5	79·8
December ...	81·0	81·3	81·3	81·3	80·9	80·8	80·2	80·0	79·6	79·4	79·2	79·2	79·0	79·0	78·6	78·4	78·1	78·1	77·9	78·2	78·7	79·5	80·1	80·7	79·6
Hourly means	81·5	81·7	81·8	81·8	81·6	81·5	81·1	80·9	80·7	80·5	80·3	80·1	79·9	79·8	79·5	79·4	79·2	79·1	78·9	79·1	79·6	80·2	80·7	81·3	80·4

V. *On Periodical Laws discoverable in the mean effects of the larger Magnetic Disturbances. By Lieut.-Colonel* EDWARD SABINE, *R.A., Treas. & V.P.R.S.*

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IN the preface to the first part of the first volume of the "Observations on days of unusual Magnetic Disturbance at the British Colonial Observatories," published in 1843, and in the introductory comments prefixed to the first volume of the "Observations at the Toronto Observatory," published in 1845, I stated the reasons which induced me to believe that the magnetic disturbances of large amount and occasional occurrence, designated in the Report of the Committee of Physics of the Royal Society as the "irregular variations," and perhaps more commonly known by the name of magnetic storms or shocks, would be found, when studied in their *mean* effects on the local magnetic direction and force extending over a sufficient period of time, to have a character of *periodicity*, which if established, would leave no doubt as to the class of magnetic phenomena to which they should be considered to belong. The opinion thus expressed resulted from an examination to which I had subjected the series of two-hourly observations of the Declination in 1841, made simultaneously at Toronto and at Hobarton, and those of 1842 at Toronto; (the corresponding observations for 1842 at Hobarton not having reached England in sufficient time to be included in the examination). Short as this period was, the evidence of the existence of laws of periodical action, connecting the effects of causes operating for the most part simultaneously at distant parts of the globe with the seasons of the year and the hours of the day at particular stations, was sufficiently systematic to induce me to regard this branch of inquiry as a most hopeful one, but as requiring for its prosecution a longer continuance of observations than had been at that time provided for. At Toronto and the other observatories under the Ordnance Department, hourly observations were substituted in 1842 for the two-hourly series previously adopted. It had appeared desirable at the commencement of these establishments not to overcharge them with work; but as it became obvious that whenever a physical theory should be brought forward to explain the phenomena which were the subjects of observation, such as, for example, those of the *diurnal variation*, there would be an immediate demand for the variation observed *at least* at *every* hour, arrangements were made, in the *spirit* of the Royal Society's Instructions, to secure a better provision for the requirements of theory than had been contemplated by the *letter* of those Instructions, and with this view observations at every hour were substituted for observations at every two hours. The series at Hobarton (under the Admiralty) had been made hourly from its commencement, the personal establishment left by Sir James Clark Ross having been calculated with that view*.

Having lately examined the hourly simultaneous observations of the Declination at Toronto and Hobarton for the years 1843, 1844 and 1845, in the course of their preparation for the press, I have had great satisfaction in finding that they confirm in a remarkable degree the anticipations which I had formed. The general evidence of periodicity, connected with the seasons of the year and the hours of the day in the mean effects at these two distant stations, of causes which yet operate for the most part simultaneously at both, thus furnished by a series of hourly observations continued for three years, is far too systematic, and rests on a basis of too long duration to make it probable that it will be otherwise than confirmed by the continuation of the series in the subsequent years; although the exact periods, and the mean numerical values of the effects produced, or their proportions to each other in the different seasons and at the different hours may, and doubtless will, receive modifications. The term "irregular" can therefore no longer be considered as correctly applied to this remarkable branch of the magnetic phenomena, which studied in their effects must now be regarded as included in the class of "periodical variations." However (apparently) irregular may be the times of their occurrence, as general phenomena affecting contemporaneously parts of the globe most distant from each other, their *effects* at those stations are found to be subject to periodical laws connected with local seasons and local time, indicating a relation directly or indirectly to the sun's place in the ecliptic, and to the earth's diurnal rotation on its axis, and producing a sensible mean effect on the magnetic direction in conformity with their own peculiar laws.

The practical bearing of this conclusion on investigations of a most interesting and valuable character which have recently been brought before the Royal Society, regarding the peculiarities of the diurnal variation in different parts of the globe and their physical explanation, will be evident, when it is considered that we have thus in each day or period of twenty-four hours *two* periodical variations, with laws, as will be seen in the sequel, extremely dissimilar. What commonly has received the name of the "diurnal variation" of the magnetic elements, is their variation at different hours of the twenty-four from a mean value obtained by summing the hourly observations and dividing the sum by their number; or, otherwise expressed, and with reference to the magnetic *direction* only, it is the figure described by either extremity of a free needle in the course of a day, under the influence of *all* causes that may influence its position, and taken on an average of a sufficient number of days to make the figure a fair mean representation. This is the "diurnal variation," as shown by observation at different seasons and at different parts of the globe, which it has been Mr. FARADAY'S object, in papers recently read before the Society, to explain physically. But the variation thus observed is in fact constituted by two variations superimposed upon each other, having different laws, and bearing different proportions to each other in different parts of the globe. At tropical stations the influence of what have been hitherto called the "irregular disturbances" is comparatively feeble, and their periodical effects may be therefore less deserving of attention; but it is otherwise at stations situated as are Toronto and Hobarton, where their influence is both really and proportionally greater, and already amounts to a clearly recognizable part of the whole diurnal variation; and it must be very far otherwise at stations which still more nearly approach those localities on the globe, where disturbances of this class become much greater than either at Hobarton or Toronto. As these localities are approached, the mean diurnal variation must be expected to partake more and more of the law by which the effects of those disturbances are regulated; and if that law be different, as it will be shown to be in the instances adduced in this paper, from another law also shown to exist, and by which another portion of the diurnal variation is governed, it may become necessary, and most probably will become necessary, at such stations, to separate, approximately at least, the effects so regulated by different laws in order to study their respective physical causes.

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* The change from two-hourly to hourly observations was accomplished at the Ordnance observatories by adding, with permission of the Master-General of the Ordnance, one non-commissoned officer to the previous strength of the establishment. The extra pay of this artillery soldier for the particular service on which he was employed was fifteen pence a day, or £22 16*s.* 3*d.* a year. This is mentioned because it is not generally known at how small an expense, services of this nature within the competency of the military force stationed in the colonies, can be rendered, whilst the men who are so employed are available for military duty at any moment that may be required.

The Instructions of the Royal Society, which were written before the periodical character of the so-called "irregular" variations was suspected, contemplate that by a sufficiently long continuance of the observations the effects of the "irregular variations" will be self-compensatory. "The observations," it is said, "must be long-continued at the same hours, before we can be assured that the irregularities do not sensibly affect the mean results." But since the true character of the disturbances is now more correctly known, it becomes obvious that no continuance of the observations will render their influence insensible: and the simplification of the problem, in the solution of which Mr. FARADAY is engaged, will require the separation, as far as may be practicable, especially in the higher latitudes, of the two classes of variation which have distinct laws, and therefore probably distinct immediate causes. I venture therefore to hope for the indulgence of the Royal Society in an endeavour to establish the fact of a distinct law of periodical action in the disturbances of occasional occurrence and unusual amount,—to show its general and remarkably analogous character at two stations separated from each other nearly as widely as two stations can be on the surface of the globe, and approximately at least to separate the mean diurnal variations at those two stations into their respective components.

The stations of Toronto and Hobarton are well-situated to furnish observations to be employed in the investigation which forms the subject of this paper. Both stations are very nearly in the same latitude, but in different hemispheres as respects the equator, and are both extra-tropical; they also differ about fifteen hours of longitude from each other. Simultaneous observations occurring in the winter months of the one station fall therefore into the summer months of the other; and the day observations of the one are for the most part the night observations of the other. The clocks which gave the time for the observations were regulated at both stations to show the mean solar time of the meridian of Göttingen, $9^h\ 15^m$ west of Hobarton, and $5^h\ 55^m$ east of Toronto. The observations were made at the completion of every hour of mean solar time at Göttingen. By this pre-arrangement the whole body of observations during the three years would have been synchronous in respect to absolute time, but for the circumstance that no observations were made on the Sundays, the Christmas days and the Good Fridays; all which days being regulated, agreeably to the purposes for which they were excepted, by *local* time, it followed that in consequence of the difference of meridians between the two stations, there were fifteen observations in each of fifty-four days of each year at each station which had no corresponding observations at the other station. The proportion of these to the whole body of observations is about one-ninth; consequently about eight-ninths of the whole were as strictly synchronous as such observations can conveniently be made. As it is not the object of this paper to examine the precise degree in which the so-called irregular disturbances are synchronous in different parts of the globe, I do not permit myself to enter into details on this part of the general subject, reserving such details for a more appropriate occasion; I will merely state generally that the evidence of the synchronous character of the disturbances afforded by the observations of these three years is not less remarkable than has been stated on other occasions; and I will proceed at once to their distribution into the months and hours of their respective occurrence, first at Toronto and then at Hobarton, and to the evidence afforded thereby of the periodical influence by which their mean effects appear to be governed.

The disturbances to be examined are those which, occurring only occasionally, and apparently irregularly, are indicated by the wide departure of the magnetic instruments from their mean or normal positions at the same hours and at the same period of the year. It is no doubt probable that the causes in which they originate do also produce smaller disturbances of the same class and apparently irregular occurrence; but no characteristics have yet been established by which the smaller disturbances of this class may be distinguished from irregularities in the action of causes of known periodical character and regular occurrence. That such characteristics may exist and may hereafter be recognized, so as to become the subjects of observation and a means of effecting a complete separation between the two classes of phenomena, is also probable; but it is not necessary to wait till then in order to assure ourselves that the larger disturbances, viz. those which may be separated from the others by their magnitude alone, are, notwithstanding their seeming irregularity, subject in their mean values to periodic laws, which are quite distinct from those of any class of disturbances or variations previously recognized; whilst the very large amount of a great portion of them affords a security that the character of their laws of periodicity, derived by a separation in which magnitude alone is regarded as the distinguishing circumstance, is not likely to undergo any material alteration (although the mean numerical values may be slightly altered), should an improved method of discrimination lead hereafter to a more perfect classification.

The magnitude of a disturbance being thus taken as a characteristic feature of the class to which it should be referred, it became a question where the line of separation should be drawn; it was desirable that on the one hand the proportion of separated observations should be ample for the intended purposes of generalization; and that on the other hand the line should be taken sufficiently distant from the mean or normal position, to exclude from the separated observations the disturbances which as far as could be judged might belong to another class. On examination, however, it soon appeared that it was not necessary to be very particular, either at Toronto or Hobarton, in selecting the distance at which the line of separation should be drawn on either side of the normal; the disturbances of *very* considerable magnitude were so numerous, and so far exceeded in amount any changes of regular occurrence, as to make it a matter of very minor importance whether a few more or a few less were comprehended at the lower end of the separated class; and after one or two trials, in which the number of separated observations was varied, but the conclusions were found to be substantially the same, five scale divisions (or 3'·6 in arc), on either side of the mean or normal position of the declination magnet at the same hour and in the same month, were adopted as a convenient distinctive value for a disturbance of the larger class at Toronto.

The number of observations thus separated amounted in the three years (1843, 1844 and 1845) to 1650. The number of hours at which observations should have been made in the three years, exclusive of Sundays, Christmas days and Good Fridays, is 22,392, and the number of hours at which observations were actually made is 22,376, sixteen observations only in the three years having been either missed or being otherwise imperfect; the proportion which the number of separated observations bears to the whole number observed is therefore one in 13·6; and we are thus furnished with an approximate measure, on the average of the three years, of the frequency with which the declination magnet is liable to be disturbed to a certain amount at Toronto, when we say that if observations are made at regular intervals, one observation in every 13·6 on the average may be expected to differ as much as 3'·6 from the true mean position corresponding to the hour and season. In 1843 there were 472 disturbed observations; in 1844, 612; and in 1845, 566; whence we may infer that 1843 was the least disturbed year of the three, and 1844 the most so: and for the purpose of assigning numerical proportions, if the degree of disturbance in 1845 be taken as unity, that of 1844 will be expressed by 1·08, and that of 1843 by 0·84. It ought to be one of the results of the system of simultaneous observation so generally adopted in the years referred to, that numerical values of this nature, derived from a sufficiently extensive induction, should be comparable with each other, and should assist in determining the great questions, whether disturbances of the class under consideration are wholly general or only partially so; and whether their greater prevalence in particular years, as shown by the observations of any one of the observatories, is to be regarded as a general, or as a local, phenomenon.

If we refer the 1650 disturbed observations to the respective months in which they occurred, the numbers are severally as follows:—

Table I.

January	87	July	173
February	101	August	199
March	123	September	232
April	182	October	146
May	130	November	103
June	87	December	97

There are two minima, January and June; the numbers increase from the minimum in January to a maximum in April, and decrease to the second minimum in June; they then increase again to a second maximum in September, followed by a decrease to the minimum in January. The September maximum is greater than the April maximum. If the year be divided into six months of summer and six months of winter, the six summer months, *i.e.* April to September inclusive, have 1003 disturbed observations; and the winter months, *i. e.* October to March inclusive, 657. If the division be into quarters, solstitial and equinoctial, the two equinoctial quarters have the higher numbers, but the summer solstitial quarter (390) is very little less than the spring equinoctial (406); the principal contrast is between the autumn equinoctial quarter (577), and the winter solstitial (287).

If we divide the 1650 disturbed observations occurring in the three years into two portions, one containing the easterly disturbances, or those of the north end of the magnet towards the east, and the other containing the westerly disturbances, we find the number to be 897 easterly and 753 westerly; the easterly preponderating in the proportion of 1·19 to 1.

If we refer the easterly and westerly disturbances separately to the respective months of their occurrence, we have the numbers as follows:—

Table II.

Months.	Easterly.	Westerly.	Months.	Easterly.	Westerly.
January	39	48	July	111	62
February	50	51	August	106	93
March	66	57	September	132	100
April	102	80	October	74	72
May	67	63	November	45	58
June	62	25	December	43	54

Whence we perceive, that whether we regard the separate account of the easterly or of the westerly disturbances, we find the numbers increase from a minimum in January to a maximum in April, and decrease to a second minimum in June; that they then commence afresh to increase to a maximum in September, and thence decrease to the minimum in January. With the exception of a small excess of easterly disturbances in July in comparison with August, the progression, which has been found to take place when the combined easterly and westerly disturbances were under consideration, is found to be the same when the separate portions are examined. The minima of each progression are in January and June; the maxima in April and September.

Distinct from this is the conclusion we may obtain if we make an intercomparison of the numbers in the respective columns of easterly and westerly disturbances. By this intercomparison we are led to perceive that in November, December and January, the number of westerly disturbances exceeds the number of easterly; that in the adjacent months on either side, viz. in October and February, the number of each is nearly equal; and that in all the other months of the year the easterly disturbances predominate; the predominance being greatest in June and July. Thus we observe that the causes which produce large easterly deflections of the north end of the magnet, when compared with those which produce westerly deflections, are most influential in June and July, and least so in December and January. Hence, it happens, that the June minimum of westerly disturbance is less than the January minimum, and is the minimum of the year in that portion of the disturbed observations; whilst the January minimum is less than the June minimum of easterly disturbance, and is the minimum of the year in that portion. We find also in the excess of easterly disturbances in June and July, a probable explanation of the small apparent irregularity already noticed in the progression of the monthly numbers in the easterly disturbances, wherein a small excess appears in the July numbers in comparison with those of August. The excess in the total number of disturbed observations in the summer quarter over the winter quarter, appears also to be due to the excess of easterly disturbances occurring in the summer quarter; for if we regard only the westerly disturbances, we find their numbers to be even somewhat greater in winter than in summer (westerly disturbances, November to February, 160 : May to July, 150 : easterly disturbances, November to February, 127 : May to July, 240).

If we now pass to the distribution of the 1650 disturbed observations into the respective *hours* of their occurrence, and seek in the numerical relations which may be thus manifested the evidence which they may afford of the existence of a *diurnal* affection, we may in the first instance examine the number of disturbed observations occurring in each of the hours, independently of the question of whether they are easterly or westerly disturbances: they are as follows:—

TABLE III.

Hours of Toronto time.	Number of disturbed observations.	Hours of Toronto time.	Number of disturbed observations.	Hours of Toronto time.	Number of disturbed observations.
6 A.M.	81	2 P.M.	37	10 P.M.	96
7 A.M.	72	3 P.M.	45	11 P.M.	72
8 A.M.	58	4 P.M.	44	Midnight ...	89
9 A.M.	66	5 P.M.	35	1 A.M.	83
10 A.M.	71	6 P.M.	46	2 A.M.	78
11 A.M.	69	7 P.M.	62	3 A.M.	80
Noon	61	8 P.M.	77	4 A.M.	78
1 P.M.	55	9 P.M.	101	5 A.M.	90

It is obvious at first sight from this Table that there is a great disparity in the occurrence of disturbed observations during the day and during the night; from 7 A.M. to 6 P.M. inclusive, the average number in each hour is 55, and from 7 P.M. to 6 A.M. inclusive, 82; but the principal contrast is between the hours of the afternoon and those of the night; the average of the five hours, from 2 to 6 P.M., being only 41, or exactly the half of the average of the night hours, 7 P.M. to 6 A.M. But this irregularity of distribution in respect to hours becomes far more striking when the disturbed observations are separated into easterly and westerly disturbances. Commencing with the easterly, we have the following Table:—

TABLE IV.

Hours of Toronto Time.	Number of Easterly disturbances.	Hours of Toronto time.	Number of Easterly disturbances.	Hours of Toronto time.	Number of Easterly disturbances.
6 A.M.	36	2 P.M.	10	10 P.M.	83
7 A.M.	36	3 P.M.	8	11 P.M.	57
8 A.M.	19	4 P.M.	12	Midnight ...	67
9 A.M.	23	5 P.M.	15	1 A.M.	54
10 A.M.	25	6 P.M.	27	2 A.M.	43
11 A.M.	30	7 P.M.	45	3 A.M.	39
Noon	19	8 P.M.	65	4 A.M.	35
1 P.M.	21	9 P.M.	86	5 A.M.	43

Here we perceive that when the easterly disturbed observations alone are considered, the disproportion of the occurrence in the hours of the day and of the night is much increased, the average number in each hour, from 7 A.M. to 6 P.M. inclusive, being only 20·5, whilst from 7 P.M. to 6 A.M. inclusive it is 54·5. But the hours which are contrasted in an especial degree are from 2 to 6 P.M. inclusive, and from 8 P.M. to 1 A.M. inclusive; the average number of easterly disturbances in each of the five hours, from 2 to 6 P.M., being 14, and in each of the six hours, from 8 P.M. to 1 A.M., 69: the minimum number occurring from 2 to 4 P.M. and the maximum at 8 and 9 P.M.

If we now turn to the westerly disturbances, as shown in the next Table, we find —1st, that they have their minima at the hours when the easterly disturbances have their maxima; and 2nd, that they do not appear to have so marked an epoch of maximum occurrence as do the easterly disturbances.

Table V.

Hours of Toronto time.	Number of Westerly disturbances.	Hours of Toronto time.	Number of Westerly disturbances.	Hours of Toronto time.	Number of Westerly disturbances.
6 A.M.	45	2 P.M.	27	10 P.M.	13
7 A.M.	36	3 P.M.	37	11 P.M.	15
8 A.M.	39	4 P.M.	32	Midnight ...	22
9 A.M.	43	5 P.M.	20	1 A.M.	29
10 A.M.	46	6 P.M.	19	2 A.M.	35
11 A.M.	39	7 P.M.	17	3 A.M.	41
Noon	42	8 P.M.	12	4 A.M.	43
1 P.M.	34	9 P.M.	15	5 A.M.	47

In the next Table I have placed the excess in the number of westerly over the easterly disturbances, or of easterly over westerly disturbances, at every hour of the day and night.

Table VI.

Hours of Toronto time.	Excess in the number of disturbed observations.	Hours of Toronto time.	Excess in the number of disturbed observations.
6 A.M.	9 Westerly.	6 P.M.	8 Easterly.
7 A.M.	0	7 P.M.	28 Easterly.
8 A.M.	20 Westerly.	8 P.M.	53 Easterly.
9 A.M.	20 Westerly.	9 P.M.	71 Easterly.
10 A.M.	21 Westerly.	10 P.M.	70 Easterly.
11 A.M.	9 Westerly.	11 P.M.	42 Easterly.
Noon	23 Westerly.	Midnight ...	45 Easterly.
1 P.M.	13 Westerly.	1 A.M.	25 Easterly.
2 P.M.	17 Westerly.	2 A.M.	8 Easterly.
3 P.M.	29 Westerly.	3 A.M.	2 Westerly.
4 P.M.	20 Westerly.	4 A.M.	8 Westerly.
5 P.M.	5 Westerly.	5 A.M.	4 Westerly.

We have in this Table a striking illustration of the periodical character of the larger disturbances, in the very different proportion of the numbers of easterly or westerly disturbances prevailing at the different hours. During the hours of the day, or notably from 8 A.M. to 4 P.M., westerly disturbances preponderate, whilst during the hours of the night, or notably from 7 P.M. to the early morning, easterly disturbances preponderate. The average excess in the number of *westerly* disturbances is 19 in each of the nine hours, constituting the former period (8 A.M. to 4 P.M.), and of easterly disturbances 48 in each of the seven hours constituting the latter period (7 P.M. to 1 A.M.). The greatest excess of easterly disturbance occurs at 9 and 10 P.M., when about seven-tenths of the whole number of disturbed observations consists of deflections of the north end of the magnet towards the east.

It is obvious from this systematically unequal distribution in the number of easterly and westerly disturbances of large amount at the different hours of the twenty-four, that unless it should be found on examination that the inequality in the proportion of the *numbers* should be counterbalanced by a similar inequality, but in the opposite direction, of the *values* of the easterly and westerly disturbances, the general result of the disturbances of this class, viz. those of large amount, must be to produce a *mean diurnal variation* of a distinct character from that which is usually known as such; inasmuch as the periodical law indicated by the last Table is very different in the hours of easterly and westerly deflection, and in those of maxima and minima, or the turning-points, from the law of the diurnal variation derived from the whole body of the observations. The correct inference will then be, that the larger disturbances have a periodical law of their own, regulating their mean effects, and influential on the mean direction of the magnet at different hours of the twenty-four; and that this law is not the same as the periodical law derived from the other observations from which they have been separated. For the purpose of examining this question, which, for the reason already stated, requires that the mean numerical values of the larger disturbances at the several hours should be sought out, I have had the mean diurnal variation for the years 1843, 1844 and 1845 at Toronto computed in two different ways, viz.—1st, from the whole body of the hourly observations, no observation whatsoever being omitted; 2nd, from the same observations, omitting the 1650 disturbances of largest amount separated in the manner described in this paper; that is to say, from the 20,726 remaining observations. In the difference between the two we have the mean diurnal variation produced by the larger disturbances, estimated on the average of the whole period of three years: it is shown in the following Table:—

TABLE VII.

Hours of Toronto time.	Mean diurnal variation produced by the larger disturbances.	Hours of Toronto time.	Mean diurnal variation produced by the larger disturbances.
6 A.M.	0′·02 West.	6 P.M.	0′·16 East.
7 A.M.	0·02 West.	7 P.M.	0·28 East.
8 A.M.	0·10 West.	8 P.M.	0·56 East.
9 A.M.	0·09 West.	9 P.M.	0·79 East.
10 A.M.	0·06 West.	10 P.M.	0·75 East.
11 A.M.	0·01 East.	11 P.M.	0·42 East.
Noon	0·09 West.	Midnight	0·36 East.
1 P.M.	0·02 West.	1 A.M.	0·33 East.
2 P.M.	0·04 West.	2 A.M.	0·20 East.
3 P.M.	0·08 West.	3 A.M.	0·14 East.
4 P.M.	0·03 West.	4 A.M.	0·03 East.
5 P.M.	0·05 East.	5 A.M.	0·00

A glance at this Table is sufficient to show that the periodical law which governs the larger disturbances is quite as clearly manifested, and its systematic character as clearly evidenced, when their mean numerical values are substituted for the numbers of easterly or westerly disturbances occurring at the different hours. It will be best to reserve any further comments until the results have been stated of a similar examination of the observations at the Hobarton observatory in the same three years, 1843, 1844 and 1845.

For the purpose of making this examination, it appeared desirable to separate such a number of the larger disturbed observations occurring during the three years at Hobarton (commencing with the largest), as should bear nearly the same proportion to the body of the observations from which they were separated, as had been the case at Toronto. With this view it was necessary to approximate the line of separation at Hobarton more nearly to the mean or normal position of the magnet than at Toronto; or in other words, to take a lower limit than at Toronto for the deflections of the declination magnet, either east or west of its mean position, which should be classed as belonging to the larger disturbances. The reason is twofold: first, the inclination at Hobarton is nearly 5° less than at Toronto ($-70° 38'$ at Hobarton, and $+75° 15'$ at Toronto), whilst the total magnetic force acting on the free needle is nearly the same at both stations; an equal disturbing force will therefore produce a greater deflection of the declination magnet at Toronto, from mechanical considerations, than at Hobarton; and second, that experience has fully shown that the disturbing causes themselves act with greater energy, independently of the mechanical considerations referred to, at Toronto than at Hobarton. It was soon found that a value taken at about two-thirds that at Toronto, viz. 3·4 scale divisions (or $2'{\cdot}4$ nearly in arc), would give nearly the same proportion of separated observations at Hobarton, as 5 scale divisions (or $3'{\cdot}6$ in arc) at Toronto, and this value was accordingly taken.

The number of observations thus separated was 1479; the system of observation being hourly, the total number of observations which should have been made in the three years (Sundays, Christmas days and Good Fridays excepted) is 22,392; the actual number was 21,436; the difference, 956, being occasioned partly by an interruption of several days in June and July 1843, owing to the suspension-thread of the magnet breaking, and partly by observations being occasionally missed, as the hourly system was rather heavy for the establishment which had been left to carry it on. The proportion of separated observations is therefore 1479 : 21,436, or 1 : 14·5; the proportion at Toronto being 1 : 13·6.

The 1479 disturbed observations are composed of 415 in 1843, 562 in 1844, and 502 in 1845; showing, as at Toronto, 1843 to have been the least disturbed year of the three, and 1844 the most so. Taking the number in 1845 as unity, we have the numerical proportions as follows:—

Hobarton	1843	0·83	Toronto	1843	0·84
	1844	1·12		1844	1·08
	1845	1·00		1845	1·00

This is quite as near an accordance in the proportion as it would be reasonable to expect, even on the extreme supposition of the disturbances being in all cases common to both stations, as, including the observations missed at Hobarton, between one-sixth and one-seventh of the hourly observations at Toronto were without corresponding simultaneous observations at Hobarton:—

If we now refer the 1479 disturbed observations to the respective months of their occurrence, we have the numbers severally as follows :—

TABLE VIII.

January	208	July	56
February	161	August	102
March	159	September	125
April	148	October	138
May	48	November	123
June	19	December	192

We have here plainly a law of numbers dependent upon the season of the year; but which with some points of resemblance has also some marked points of difference from the law found at Toronto. The number of disturbed observations arrange themselves at Hobarton in a single progression instead of a double progression as at Toronto. The maximum number occurs in December and January, the two midsummer months, and the minimum in May, June and July, the midwinter months. The six summer months, October to March inclusive, have 981 disturbed observations, and the six winter months, April to September inclusive, 498; or on the average nearly twice as many in each of the summer months as in the winter months; whilst at Toronto the proportion is more nearly 1·5 in the summer months to 1 in the winter months. If the year be divided into quarters, the summer solstitial quarter has the greatest number (523); then the two equinoctial quarters (respectively 468 and 365, the numbers at the autumnal equinox preponderating as at Toronto, but the autumn being in this case, February, March and April, instead of August, September and October as at Toronto); and finally, the winter solstitial quarter (123) having here, as at Toronto, a much less number of disturbed observations than the other three.

If we divide the 1479 larger disturbances into easterly and westerly portions (Table IX.), we have 613 deflections of the north end of the magnet towards the east, and 866 towards the west. The predominance is here of westerly disturbances as it was at Toronto of easterly, and as analogy would require, since the stations are in different hemispheres and the deflections are of the same end of the magnet at both. The proportion in which the westerly deflections preponderate is greater than that of the easterly predominance at Toronto, being about 1·4 : 1 at Hobarton and but 1·2 : 1 at Toronto. The westerly disturbances are in excess in every month of the year at Hobarton, whereas the excess of easterly disturbances at Toronto prevails only during seven months of the year, the westerly being in excess during the winter solstitial quarter. But with this difference there is still a considerable analogy preserved; the proportion of easterly disturbances to westerly is greatest in the summer quarter and least in the winter quarter at Toronto, whilst at Hobarton the converse proportion holds good, the proportion of westerly to easterly disturbances being greatest in the summer quarter and least in the winter quarter at Hobarton.

Table IX.

Months.	Easterly.	Westerly.	Excess of Westerly.	Months.	Easterly.	Westerly.	Excess of Westerly.
January	80	128	48	July	22	34	12
February......	73	88	15	August	47	55	8
March.........	70	89	19	September ...	50	75	25
April	69	79	10	October	58	80	22
May	16	32	16	November ...	42	81	39
June	5	14	9	December ...	81	111	30

In this comparison of the laws which appear to regulate the distribution of the larger disturbances in the several months of the year at Toronto and Hobarton, I have been desirous of giving quite as much prominency to the points of difference at the two stations as to those of resemblance; believing the one to be quite as likely to conduct to a recognition of the physical causes of these remarkable phenomena as the other. But it must be remembered that three years scarcely form a sufficient basis of observation for secure and correct deduction of the minor details of an *annual* variation, though they may be sufficient in the case of *diurnal* variation. A continuation of the comparison by a similar examination of the hourly observations at Toronto and Hobarton in the three following years, 1846, 1847 and 1848, may be expected to elucidate what may appear obscure or uncertain on the present occasion, and will enable the differences as well as the analogies of the annual laws at the two stations to be discussed on more secure grounds. I will therefore proceed to the distribution of the 1479 disturbed observations at Hobarton into their respective hours of occurrence, for the purpose of examining the evidence they may afford of a diurnal law, for the deduction of which in its main features at least three years' continuance of observation ought to be a sufficient time.

Table X. shows the number of disturbed observations occurring at each hour of the twenty-four, separating them also into easterly and westerly disturbances.

Table X.

Hours of Hobarton time.	Easterly disturbances.	Westerly disturbances.	Total.	Hours of Hobarton time.	Easterly disturbances.	Westerly disturbances.	Total.
6 A.M.	27	21	48	6 P.M.	22	20	42
7 A.M.	38	25	63	7 P.M.	11	33	44
8 A.M.	32	36	68	8 P.M.	10	50	60
9 A.M.	34	24	58	9 P.M.	9	68	77
10 A.M.	36	18	54	10 P.M.	5	66	71
11 A.M.	37	28	65	11 P.M.	7	70	77
Noon	40	33	73	Midnight ...	17	66	83
1 P.M.	41	31	72	1 A.M.	17	67	84
2 P.M.	36	22	58	2 A.M.	16	44	60
3 P.M.	36	22	58	3 A.M.	29	40	69
4 P.M.	37	17	54	4 A.M.	28	27	55
5 P.M.	25	21	46	5 A.M.	23	17	40

If we regard, first, the *westerly* disturbances, we perceive a scarcely less striking disparity in their relative numbers during the hours of the day and of the night than was found to be the case with the *easterly* disturbances at Toronto. From the early hours of the morning to 6 and 7 P.M., the average number of westerly disturbed observations is considerably less than half the average number during the hours of the night (8 P.M. to 3 A.M. inclusive); whilst the contrast is still greater (as in the case of the easterly disturbed observations at Toronto) between the hours of the afternoon (2 to 6 P.M.) and the early hours of the night (8 P.M. to 1 A.M.).

The hours of the maximum occurrence of the westerly disturbances are also those of the minimum occurrence of easterly disturbances, and the latter do not appear to have any marked epoch of maximum occurrence at other hours.

Referring back to the comments on Tables III., IV., V. and VI., the analogy between the two stations will be seen to be most striking. Laws derived directly from the phenomena, and having so much in common at stations so widely remote from each other, cannot be regarded as accidental, and claim to be viewed as a step gained in the analytical examination of the magnetic phenomena and in their classification; in the path therefore which, according to the principles of the inductive philosophy, conducts from a knowledge of effects to the perception of their cause or causes. We have traced in the largest and most influential portion of the disturbances, belonging to the class which has hitherto borne the name of "irregular," the existence of a law connecting them with the local hours of the station at which they were observed; and in the accordance of this law, as severally deduced at Toronto and Hobarton, we see reason to attribute to it a more general character than that of a mere dependence on the peculiarities of particular stations. In order that this may be more clearly seen, I have placed in the next Table a comparative view of the diurnal variation derived from the larger disturbances at Toronto and Hobarton, on the average of the three years under discussion. The phenomena at Toronto are reproduced from Table VII., and those at Hobarton have been obtained in the same manner as at Toronto, and as is described in the paragraph which immediately precedes Table VII.

TABLE XI.

Local time.	Hobarton.	Toronto.	Local time.	Hobarton.	Toronto.
6 A.M.	0′·03 East.	0′·02 West.	6 P.M.	0′·04 West.	0′·16 East.
7 A.M.	0·06 East.	0·02 West.	7 P.M.	0·16 West.	0·28 East.
8 A.M.	0·02 East.	0·10 West.	8 P.M.	0·27 West.	0·56 East.
9 A.M.	0·04 East.	0·09 West.	9 P.M.	0·39 West.	0·79 East.
10 A.M.	0·03 East.	0·06 West.	10 P.M.	0·42 West.	0·75 East.
11 A.M.	0·03 East.	0·01 East.	11 P.M.	0·41 West.	0·42 East.
Noon	0·02 East.	0·09 West.	Midnight ...	0·38 West.	0·36 East.
1 P.M.	0·04 East.	0·02 West.	1 A.M.	0·34 West.	0·33 East.
2 P.M.	0·05 East.	0·04 West.	2 A.M.	0·24 West.	0·20 East.
3 P.M.	0·06 East.	0·08 West.	3 A.M.	0·12 West.	0·14 East.
4 P.M.	0·05 East.	0·03 West.	4 A.M.	0·02 West.	0·03 East.
5 P.M.	0·01 East.	0·05 East.	5 A.M.	0·03 East.	0·00

The general character at the two stations (easterly deflections at the one being equivalent, as already stated, to westerly at the other) is strikingly accordant: the principal difference appears to consist in the mean easterly deflection at Toronto being greater in amount from 6 P.M. to 10 P.M. than the westerly deflection at Hobarton at the same hours.

The absolute quantities shown in this Table are small, but it must be remembered that they represent the *mean daily* effect of the disturbances, during the whole period of three years under discussion; while the disturbances themselves are by no means of daily occurrence. Small as the numbers are, however, they make a very important change in the character of the residual diurnal variation, both at Toronto and Hobarton, from that which is derived from the mean of all the observations including the disturbed ones. In order that this may be distinctly seen, I have placed in the following Table (XII.) the mean diurnal variation as it would be shown at each hour with and without the disturbances, and have added columns containing the amount of the change in the mean direction in the intervals from hour to hour: the extreme westerly position at Toronto and the extreme easterly position at Hobarton are taken as the respective zeros, from which the diurnal variation at the several hours is counted. The sign + in the column of differences signifies, therefore, that the north end of the magnet has moved during the interval to the east at Toronto and to the west at Hobarton, and the sign − has the contrary signification.

TABLE XII.—Diurnal variation at Toronto and Hobarton, with the disturbed observations retained, and with the same omitted; derived from hourly observations during the years 1843, 1844 and 1845.

Toronto.					Hobarton.				
Toronto mean time.	Retaining the disturbed observations.		Omitting the disturbed observations.		Hobarton mean time.	Retaining the disturbed observations.		Omitting the disturbed observations.	
Hours.	Diurnal variation.	Differences.	Diurnal variation.	Differences.	Hours.	Diurnal variation.	Differences.	Diurnal variation.	Differences.
6 A.M. ...	7′·52	+0′·91	7′·52	+0′·91	6 A.M. ...	5′·29	+0′·76	5′·26	+0′·80
7 A.M. ...	8·43	+0·24	8·43	+0·33	7 A.M. ...	6·05	+0·98	6·06	+0·93
8 A.M. ...	8·67	−0·93	8·76	−0·95	8 A.M. ...	7·03	+0·52	6·99	+0·54
9 A.M. ...	7·74	−2·25	7·81	−2·28	9 A.M. ...	7·55	−0·61	7·53	−0·62
10 A.M. ...	5·49	−2·63	5·53	−2·70	10 A.M. ...	6·94	−1·77	6·91	−1·77
11 A.M. ...	2·86	−2·08	2·83	−1·98	11 A.M. ...	5·17	−2·30	5·14	−2·31
Noon	0·78	−0·78	0·85	−0·85	Noon	2·87	−2·06	2·83	2·04
1 P.M. ...	0·00	+0·30	0·00	+0·32	1 P.M. ...	0·81	−0·70	0·79	−0·69
2 P.M. ...	0·30	+1·07	0·32	+1·11	2 P.M. ...	0·11	−0·11	0·10	−0·10
3 P.M. ...	1·37	+1·32	1·43	+1·27	3 P.M. ...	0·00	+0·90	0·00	+0·89
4 P.M. ...	2·69	+1·20	2·70	+1·11	4 P.M. ...	0·90	+1·25	0·89	+1·21
5 P.M. ...	3·89	+0·83	3·81	+0·73	5 P.M. ...	2·15	+0·95	2·10	+0·90
6 P.M. ...	4·72	+0·48	4·54	+0·36	6 P.M. ...	3·10	+0·70	3·00	+0·58
7 P.M. ...	5·20	+0·37	4·90	+0·24	7 P.M. ...	3·80	+0·69	3·58	+0·58
8 P.M. ...	5·57	+0·50	5·00	+0·26	8 P.M. ...	4·49	+0·56	4·16	+0·43
9 P.M. ...	6·07	+0·08	5·26	+0·11	9 P.M. ...	5·05	+0·35	4·59	+0·32
10 P.M. ...	6·15	−0·29	5·37	+0·05	10 P.M. ...	5·40	+0·17	4·91	+0·19
11 P.M. ...	5·86	−0·20	5·42	−0·17	11 P.M. ...	5·57	−0·05	5·10	−0·03
Midnight...	5·66	−0·12	5·25	−0·07	Midnight...	5·52	−0·29	5·07	−0·24
1 A.M. ...	5·54	−0·14	5·18	0·00	1 A.M. ...	5·23	−0·31	4·83	−0·22
2 A.M. ...	5·40	+0·17	5·18	+0·23	2 A.M. ...	4·92	−0·31	4·61	−0·19
3 A.M. ...	5·57	+0·46	5·41	+0·57	3 A.M. ...	4·61	−0·06	4·42	+0·05
4 A.M. ...	6·03	+0·55	5·98	+0·58	4 A.M. ...	4·55	+0·23	4·47	+0·29
5 A.M. ...	6·58		6·56		5 A.M. ...	4·78		4·76	

Considering Toronto in the first instance, it is obvious from this Table that the westerly retrogression, which is found to take place from 10 P.M. to 2 A.M. in the diurnal march of the magnetic declination when the whole of the observations are retained, is certainly chiefly, and probably entirely, occasioned by a return of the magnet from the disturbed position to which it had been carried by the great excess of easterly disturbances between the hours of 7 and 10 P.M.; which easterly excess rapidly diminishes after 10 P.M. When the disturbed observations are omitted, the movement of the north end of the needle towards the east after 6 P.M. is seen to be slower, and never reaches so great an easterly extreme as takes place when the disturbed observations (which it must be remembered are only of occasional occurrence) are retained and allowed to influence the daily mean. By the separation of the disturbances of principal magnitude in the manner described in this paper, the westerly retrogression at the hours referred to is in fact almost eliminated, and we can scarcely doubt that it would be entirely so, if we possessed the means of more completely separating the whole of the disturbances which belong to the same class and cause as the larger ones; and that by such separation the character of the residual diurnal variation would be entirely changed (as it is now almost entirely changed) from a double progression having two maxima and two minima, to a single progression with one easterly extreme at 8 A.M., and one westerly extreme at 1 P.M. The change in the character of the diurnal variation at Hobarton, caused by the omission of the disturbed observations, is similar in kind to that at Toronto, though not quite so strongly marked.

The change of character which thus appears to be indicated (at both stations, but particularly at Toronto) is a very important one, as will be readily admitted by those who are engaged in searching out the physical causes of these phenomena. The *nocturnal episode*, as it has been termed by Mr. FARADAY, or the retrogression of the declination during the hours of the night, would be done away as a part of the regular diurnal variation; and the physical explanation which we should have to seek would be that of a different phenomenon, namely, of an *increased* movement, *not* in the *retrograde* direction, but in the *same* direction as that of the regular diurnal variation, occurring at earlier hours of the night than those of the retrogression; being moreover of occasional and apparently fitful (as opposed to regular) occurrence,—although when the average is taken of a sufficient number of days it is found to be strictly periodical in its mean effects, and influential therefore on the mean diurnal variation of the magnet. I wish however to guard myself from being understood to oppose, by these remarks, the supposition that has been made of the existence of physical causes acting during the night antagonistic to those of the day: there may still be room for a supposition of this nature; for admitting the apparent retrogression to be greatly lessened if not entirely eliminated by the withdrawal of the influence of disturbances of occasional occurrence, still it continues to be true that the progression of the residual diurnal variation which commences at an early hour of the afternoon is *checked* during the hours of the night, even if it be not at any moment actually reversed.

Although conclusions which are drawn from hourly observations, continued during three years at two stations, scarcely seem to require the support they may receive from their agreement with inferences previously drawn resting on a much narrower basis, yet it may not be unimportant to recall those, derived from a similar investigation to the present into the two-hourly observations at Toronto in the years 1841 and 1842, which were published by me in 1845 in the Comments on the Observations of those years contained in the first volume of the Toronto Observatory. After remarking that the deflections produced by the disturbances are of sufficient magnitude and regularity of occurrence to constitute a recognizable and systematic component part of the mean diurnal variation obtained from observations of a month's continuance or more, I stated as follows: "By their easterly maximum at 10 P.M. (together with the increasing prevalence of easterly deflections at the previous hours of 6 and 8), there is superinduced an excess of easterly direction at those hours, which appears to be in great measure the cause of the westerly retrogression of the magnet at the succeeding hours of midnight and 2 A.M.; and we are thus led to infer the probability, that if the whole effect of the disturbing cause, or causes, could be eliminated, the residual portion of the diurnal variation might appear as a single progression with but one maximum and one minimum in the twenty-four hours.

"The connection which thus appears between the systematic operation of the disturbances and the occurrence of a double progression in the diurnal variation, would lead to an important inference in regard to the disturbances themselves, to which it may be well to advert, in order that the subject may receive further examination by the observations of other observatories. The hours of the night at which the otherwise continuous easterly march of the diurnal variation is interrupted, appear to be the same, or very nearly the same, at all the observatories at which results have yet been published. If this interruption be either wholly, or in great measure, occasioned by the influence of the disturbances, operating in a systematic manner, as they are found to do at Toronto, the deflections which they produce at other stations must also have a similar systematic character, and be connected, as those of Toronto are, with the hour of the day at the particular station.

"We should in such case arrive at the important conclusion, that whilst the disturbances must be attributed to general causes, inasmuch as they are found to prevail on the same days in different and very remote parts of the globe—it must also be recognized, that their operation, in every particular locality, is regulated by a law which respects the hours of the place."

The investigation, which has been the object of this paper, is obviously incomplete until a similar examination shall have been made of the influence of the larger disturbances on the mean diurnal variation of the Inclination and of the total Force. I may perhaps hope to make such an investigation the subject of a future communication.

VI. *On the Relation of the Air and Evaporation Temperatures to the Temperature of the Dew-Point, as determined by Mr.* Glaisher's *Hygrometrical Tables, founded on the Factors deduced from the six-hourly observations made at the Royal Observatory, Greenwich. By* John Fletcher Miller, *F.R.S., F.R.A.S., Assoc. Inst. C.E. &c. Communicated by Lieut.-Col.* Sabine, *For. Sec. R.S.*

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Remarks.

Of all the instruments observed and recorded by the meteorologist, the hygrometer is in many respects the most valuable, both in a scientific and practical point of view; for, by a simple knowledge of the point at which the atmosphere can contain no more vapour without precipitation at its existing temperature, and which is called the point of saturation or temperature of the dew-point, many other highly important collateral conditions, such as the elastic force of vapour, the weight of vapour in a cubic foot of air, and the additional weight required for complete saturation at all temperatures of the air, the relative degree of humidity, and the weight of a cubic foot of air under the ever-varying circumstances of heat, moisture and pressure, may readily be obtained, either by well-known formulæ, or by inspection from tables prepared for the purpose. But the hygrometer is also of no small value in the arts and in the practical concerns of life: as a prognosticator of the weather it stands second to no other instrument except the barometer, which it often rivals in the faithfulness of its movements; whilst the condition of the air as to moisture or dryness is acknowledged by all physicians to have no slight effect on the human body, both in its normal and abnormal state; but more especially are its influences visible on the frame of the invalid, either in aiding to restore healthy functions, or in promoting the exacerbation of disease.

It is therefore of no small moment that scientific observers, at least, should possess an instrument by which that important element, the dew-point, can be accurately and expeditiously obtained.

Dalton and other old meteorologists made use of glass vessels filled with spring water, which retains a nearly uniform temperature throughout the year; and, in the summer months, it was generally found sufficient to cause a deposit of moisture on the outside surface of the glass. In winter, ice or snow was mixed with the water, or when the temperature was very low, freezing mixtures were employed.

The dew was carefully wiped from the surface of the vessel as long as it continued to form, and the moment it ceased, the temperature of the water was carefully noted and recorded as the existing dew-point.

This rough and tedious method has however long been superseded by the use of that beautiful and delicate apparatus bearing the name of the late Professor Daniell, which gives the dew-point at once in degrees of Fahrenheit's scale. Highly valuable as this instrument unquestionably is, it is yet open to some objections, more especially in the hands of non-scientific persons.

1st. The reduction of the air temperature to that of the dew-point is effected by the rapid evaporation of sulphuric ether from a hollow ball of glass covered with fine muslin. Now ether is rather an expensive material, and it is essential that it should be unadulterated and of the strongest description, and such cannot always be obtained, even in large towns. An old established and respectable druggist tells me, that until recently (and the practice probably still exists in many places) it was the invariable custom of the trade to mix one part of spirits of wine with every two parts of ether. And I remember examining some ether in use by a young friend who professed to take hygrometrical observations with this instrument, which I should say contained a still larger proportion of alcohol in combination with *water*. This analysis of its composition is based on the fact that it might be used *ad libitum*, without depressing the temperature more than two or three degrees. Long experience has convinced me, that unless the evaporating fluid be pure, the results, if obtained at all, cannot be depended upon. The Ether rect. fort. should, if possible, be employed.

2nd. Some experience, great care and a quick eye, are requisite to secure accurate observations, and to catch the temperature at the exact moment when the annulus of dew begins to form on the dark bulb in the plane of the internal liquid surface.

3rd. If the ether be dropped on the bulb too quickly, too high a dew-point will be obtained. The ether phial should be fitted with a small siphon, and the heat communicated to the fluid by the hand will be sufficient to force it out slowly in drops.

4th. The atmosphere may be so exceedingly dry, particularly in the months of April and May, that no quantity of ether, even of the best kind, will suffice to reduce the temperature to the point of saturation. And this is more especially the case in warm climates, where this fluid deteriorates most rapidly by keeping. At sea, in tropical latitudes, I have sometimes been unable to find the dew-point with Daniell's instrument for two or three consecutive days.

Such instances are however rare in this country; when they occur, freezing mixtures must be had recourse to, but I have very seldom had occasion to use them. The greatest difference I have ever observed between the temperature of the air and the dew-point, was 28°, on the 27th of April, 1842. The highest dew-point I have recorded was 68°, on the 17th of August, 1843, with 7·53 grs. of vapour in a cubic foot; the lowest was 8°, on the 14th of February in the same year, the air temperature being 26°, and the weight of vapour in a cubic foot only 0·87 gr.

The dry- and wet-bulb thermometers, as a means of obtaining the dew-point, did not come into use until many years after the invention of Daniell's instrument, and from the want of correct tables, based on an accurate knowledge of the relation existing between the air and evaporation temperatures and the temperature of the dew-point, they were, until recently, of comparatively little service to the scientific observer.

When the magnetic and meteorological observatory was, at the suggestion of the Royal Society, established at Greenwich, two-hourly observations of the dry- and wet-bulb thermometers began to be taken, whilst the dew-point from Daniell's hygrometer was recorded every six hours, simultaneously with the temperature of the dry and wet bulbs; and these readings have been continued up to the present time. Such frequent observations, made by careful and competent observers with the best instruments, could not fail in time to afford the requisite data for the computation of an empirical dew-point, at all known temperatures of the air. The volume of Greenwich Magnetical and Meteorological Observations (copies of which the Astronomer Royal is kind enough to send me) for 1843, contains a complete discussion of the results down to 1845, from which the following factors were deduced:—

When the temperature of the air is	below 24°	the difference between the temperature of evaporation and the temperature of the air multiplied by	8°·5	gives the difference between the temperature of the air and the temperature of the dew-point.
Between	24° and 25°	„	7°·3	„
Between	25 and 26	„	6·4	„
Between	26 and 27	„	6·1	„
Between	27 and 28	„	5·9	„
Between	28 and 29	„	5·7	„
Between	29 and 30	„	5·0	„
Between	30 and 31	„	4·6	„
Between	31 and 32	„	3·6	„
Between	32 and 33	„	3·1	„
Between	33 and 34	„	2·8	„
Between	34 and 35	„	2·6	„
Between	35 and 40	„	2·5	„
Between	40 and 45	„	2·3	„
Between	45 and 50	„	2·1	„
Between	50 and 55	„	2·0	„
Between	55 and 60	„	1·8	„
Between	60 and 65	„	1·8	„
Between	65 and 70	„	1·7	„
	above 70	„	1·5	„

From these data, Mr. Glaisher, of the Royal Observatory, in the year 1847, calculated, arranged and printed, at his own cost, an elaborate series of tables, showing, at a glance, the relation of the *temperature of evaporation* to that of the dew-point at every degree of the air temperature, from 10° to 90°; also the elastic force of vapour, weight of vapour in a cubic foot, the remaining quantity required for complete saturation, the relative degree of humidity, and the weight in grains of a cubic foot of air, under the varying conditions of heat, of humidity and of pressure.

Notwithstanding a conviction of the accuracy of Mr. GLAISHER's tables, both from the well-known character of the chief observer and compiler, and the favourable circumstances under which the elements were obtained, yet having found similar tables defective, and having used DANIELL's apparatus with satisfaction for many years, I felt reluctant to abandon it for the wet- and dry-bulb thermometers, slight as is the trouble of observing them, without personal experience of the correctness of the tables by which the dew-point was to be eliminated.

Accordingly, I sent up my DANIELL's hygrometer to Greenwich for comparison with the observatory standard thermometer, and, at the same time, Mr. GLAISHER kindly procured me a pair of delicate thermometers on the same metal frame, selected from a number of others, and made by BARROW of Oxenden Street. These thermometers were considered to have identical readings under similar circumstances, and both to agree with the Greenwich standard. The dew-point thermometer was also found to be generally correct, the errors mostly amounting to small fractions of a degree.

With these instruments the observations embodied in the annexed Tables were made in the years 1847 and 1848, the hours of observing being 11 o'clock in the morning, and 3 o'clock in the afternoon.

Hygrometrical state of the Atmosphere at Whitehaven, in the year 1847.

1847.	Dry bulb.			Wet bulb.			Dew-point.								
							Deduced.			Observed.					
													Compt. of dew-point.		
	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.m.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
January	36·64	38·61	37·62	......	......	......	......	......	......	32·50	33·82	33·16	4·14	4·79	4·46
February.........	37·17	39·64	38·40	......	......	......	......	......	......	31·14	32·10	31·62	6·03	7·54	6·78
March............	43·13	46·34	44·88	......	......	......	......	......	......	36·03	36·09	36·06	7·10	10·25	8·82
April	45·68	47·75	46·71	......	......	......	......	......	......	38·55	39·53	39·04	7·13	8·22	7·67
May	55·70	57·23	56·46	51·46	52·82	52·14	48·40	49·50	48·95	47·96	49·25	48·60	7·74	7·98	7·86
June	59·85	61·75	60·80	54·96	55·63	55·29	51·50	51·00	51·25	51·43	50·98	51·20	8·42	10·77	9·60
July...............	64·98	67·46	66·22	59·96	61·36	60·66	57·00	57·80	57·40	57·11	57·66	57·38	7·87	9·80	8·84
August	61·53	62·70	62·11	56·87	57·56	57·21	53·90	53·78	53·84	53·95	53·78	53·86	7·58	8·92	8·25
September	55·03	56·26	55·64	50·96	51·11	51·03	48·20	47·30	47·75	47·82	46·68	47·25	7·21	9·58	8·39
October	54·09	53·82	53·95	50·88	50·37	50·62	48·20	46·80	47·50	48·02	47·04	47·53	6·07	6·78	6·42
November	49·85	50·50	50·17	47·59	48·26	47·92	45·40	46·00	45·70	45·57	45·87	45·72	4·28	4·63	4·45
December	41·58	41·28	41·43	39·61	39·23	39·42	37·00	36·80	36·90	37·18	36·71	36·94	4·40	4·57	4·49
Means............	50·43	51·94	51·20	51·53	52·04	51·78	48·73	48·62	48·66	43·93	44·12	44·03	6·50	7·82	7·17
				Mean of observed dew-point					48·56	From May ...		48·56			

Hygrometrical state of the Atmosphere at Whitehaven, in the year 1848.

1848.	Dry bulb.			Wet bulb.			Dew-point.								
							Deduced.			Observed.					
													Compt. of Dew-point.		
	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.	11 A.M.	3 P.M.	Mean.
January	35°·50	36°·58	36°·04	33°·94	34°·68	34°·31	31°·50	31°·75	31°·62	31°·62	31°·85	31°·73	3°·88	4°·73	4°·30
February.........	43·16	44·06	43·61	41·85	42·60	42·22	40·12	40·83	40·47	40·05	40·72	40·38	3·11	3·34	3·22
March............	43·82	45·46	44·64	41·69	42·68	42·18	39·20	39·50	39·35	39·38	39·26	39·32	4·44	6·20	5·32
April	48·86	51·07	49·96	45·03	46·90	45·96	40·75	42·70	41·72	40·91	42·41	41·66	7·95	8·66	8·40
May	57·57	59·77	58·67	52·80	54·29	53·54	49·45	50·30	49·87	49·40	50·29	49·84	8·17	9·48	8·82
June	60·25	61·21	60·73	55·37	55·51	55·44	52·01	51·48	51·74	52·18	51·29	51·73	8·07	9·92	8·99
July	61·88	64·13	63·00	57·38	58·72	58·05	54·25	55·02	54·63	54·28	55·34	54·81	7·60	8·79	8·19
August	59·22	61·50	60·36	54·32	55·69	55·00	50·87	51·64	51·25	50·80	51·32	51·06	8·42	10·18	9·30
September	58·37	59·91	59·14	54·46	55·32	54·89	51·72	52·11	51·91	51·45	51·64	51·54	6·92	8·27	7·59
October	51·21	51·78	51·49	48·59	48·56	48·57	46·00	45·30	45·65	45·85	45·35	45·60	5·36	6·43	5·89
November	43·99	44·76	44·37	42·17	42·57	42·37	40·04	40·07	40·05	40·14	39·95	40·04	3·85	4·81	4·33
December	42·92	42·89	42·90	41·10	41·24	41·17	38·92	39·14	39·03	39·08	38·35	38·71	3·84	4·54	4·19
Means......... ..	50·56	51·93	51·24	47·39	48·23	47·81	44·57	44·98	44·77	44·59	44·81	44·70	5·97	7·11	6·54

In eight months of the year 1847, the difference between the observed and the deduced dew-point is 0°·10, and in 1848 it is but 0°·07, the mean of the two periods comprising 1220 observations, amounting to the comparatively evanescent fraction of $\frac{8}{100}$ths of a degree; and, had the instruments been *absolutely* perfect, doubtless the accordance between the two dew-points would have been still more obvious. Hence the results show, in a striking manner, the extreme accuracy of Mr. GLAISHER's Tables, and add additional testimony to the value of the Greenwich hygrometrical observations, and the resulting formula on which those Tables are founded. Being strongly impressed with the utility and importance of these tables, I am induced to give my own experimental evidence in their favour, which (coming from a wholly disinterested party) may perhaps be entitled to some weight; and, in the hope of giving them greater publicity, and of bringing them into that general use which they so well merit, I beg to lay that evidence before the Royal Society.

By means of the tables founded on the Greenwich hygrometrical observations, the combination of the dry- and wet-bulb thermometers is converted into a very delicate scientific instrument, possessing many advantages over that of DANIELL, not the least of which is, that its readings may be depended upon, even in the hands of the most inexperienced and uneducated person. Thus, observations on the hygrometrical state of the atmosphere may be obtained on mountains, at great heights above the sea, on the sea itself, in mines, and various other inconvenient localities, by those whose occupations or callings lead them to spend a considerable portion of their time in such situations. In this way illiterate persons may become truly valuable assistants to the meteorologist in his researches, and the observations secured by the shepherd, the miner, and the mariner may afterwards be turned to good account by the philosopher in his closet.

It is however necessary that the thermometers used for this purpose should be essentially good, and, if possible, that their readings should agree with each other, and with a standard instrument. But as perfect thermometers are very difficult to obtain, most of such instruments will differ from a standard at one point or other of the scale. They should therefore be carefully compared, and the errors allowed for, either at each reading, at the end of every month, or at some stated period. The goodness of the instruments, or the application of the corrections, is the more essential, as any error in either or both the thermometers is considerably increased in the resulting temperature of the dew-point. The bulbs should be carried fully an inch below the metal or wood scale. The wet bulb should be covered with book-muslin, and the best conductor of the water from the cistern to the bulb is a piece of cotton lamp-wick, which must be changed as circumstances require, as in time it is apt to lose its capillary action. In winter, the water in the vessel will frequently be frozen, and the wet bulb quite dry : in this case the bulb must be moistened, when a coating of ice will form on it, from which evaporation will take place : an hour or more will however sometimes elapse before the temperature of the moist bulb falls below that of the dry.

It is well known that evaporation goes on freely from the surface of frozen water, even when the whole mass is converted into a solid block of ice. From the 11th to the 16th of December 1846, during which a brisk breeze prevailed, the loss from my evaporation gauge was 0·450 inch, or ·075 per diem, the average of the month being but ·033 per diem. In twelve days of frost in February, 1847, the evaporation from the ice was ·552, or ·046 per day, the average daily quantity for the month being ·030. During ten days of keen frost, between the 20th and 30th of January, 1848, the ice had parted with 0·324 inch, or ·032 per diem, the average daily loss for the month being only ·024. For five days of December 1848, the loss was ·037 per diem, the daily average for the month being ·032 ; and from the 1st to the 8th of January, 1849, the depth evaporated was equivalent to ·017 per diem, the average daily loss during the month being ·029 inch. Hence it appears, that notwithstanding the large amount of heat required, not only to liquify but to vaporize frozen water, the vapour thrown off by ice in an invisible form exceeds in amount the average daily evaporation from an equal surface of water in the winter season. This apparently anomalous circumstance probably arises from the extreme dryness of the atmosphere, and its consequently increased capacity for vapour in severe frosts, whereas at other times during the winter the air is very moist near the sea, being generally not more than 2° or 3° above the point of saturation.

The subject of evaporation has been very little investigated or treated of since the publication of Mr. Howard's 'Climate of London' in the year 1818, and having paid considerable attention to this department of meteorology for several years past, I may perhaps be excused (though not directly connected with the issue of this paper) from briefly giving the results of my own investigations, obtained at nearly the opposite point of the kingdom. Evaporation is scarcely ever *entirely* suspended, either during the heaviest rains, or when the air is completely saturated with vapour; at least, I have not met with more than two or three instances in which some daily loss was not appreciable to a finely graduated metre. In severe nights, the depth evaporated in twenty-four hours will sometimes, though very rarely, reach $\frac{4}{10}$ths of an inch. On the 22nd of May, 1844, 0·430 was measured, and on a freezing mixture being applied to Daniell's hygrometer, the dew-point was found to be 24° below the temperature of the air, which was 63°. The evaporation for the month was 6·280 inches, with only a quarter of an inch of rain.

Amount of Evaporation at Whitehaven, Cumberland, in the six years ending with 1848.

Month.	1843.	1844.	1845.	1846.	1847.	1848.
	in.	in.	in.	in.	in.	in.
January	·785	·940	·935	1·015	·860	·743
February ...	1·178	1·190	·905	1·335	·843	·792
March.........	1·620	1·835	1·862	2·085	1·821	1·397
April	1·718	2·610	3·400	2·575	2·181	2·728
May	3·045	6·280	3·645	4·375	2·950	4·580
June	4·690	3·820	3·760	6·645	4·506	3·749
July............	3·125	4·495	5·455	3·450	4·726	3·935
August	3·305	2·520	3·250	3·875	3·751	3·686
September ...	3·745	3·405	3·225	2·980	2·793	2·896
October	1·940	2·270	2·360	1·780	1·688	1·549
November ...	1·030	1·554	1·760	1·360	1·107	1·129
December ...	·800	·800	1·875	1·025	1·005	1·019
Inches.........	26·981	31·719	32·432	32·500	28·231	28·203[*]

The mean amount of evaporation for the six years is 30·011 inches, and the average quantity of rain for the same period is 45·255 inches, so that the depth of the water precipitated exceeds that taken up by evaporation at the coast, in the latitude of 54½°, by 15·244 inches.

The evaporation gauge with which the above experiments were made, is a copper vessel 8 inches in diameter, and rather more than an inch and a half in depth. Half an inch of water is accurately measured and poured into the dish, and the daily loss ascertained each morning at 9 o'clock, by means of a carefully graduated tube reading to the thousandth part of an inch[†].

The evaporation dish receives a fair proportion of wind and sun, and is always exposed in the open air during the day, except when rain is falling. At night, and in wet weather, it is placed under a capacious shed, 9 feet in height, and open in front. Thus, it is conceived, that the evaporating surface is freely acted upon by all the circumstances concerned in promoting this natural process.

Mr. Howard found the evaporation near the surface of the ground in the neighbourhood of London to be about 20 inches, or 5 inches under the average fall of rain; but the gauge was constantly under cover, and consequently but little exposed to the direct rays of the sun, which will account for the great difference between the results at Whitehaven and the metropolis. Had the gauges been in all respects similarly circumstanced, the evaporation at London, from its higher mean temperature, would probably have been found to exceed the amount registered in the higher latitude.

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[*] Evaporation in 1849, 28·699 inches.

[†] Till the close of 1846, the dish was placed on a stool, 8 inches above the ground; since that period it has been placed on a stand 4 feet 4 inches in height, and just large enough to hold it.

The Observatory, Whitehaven,
October 20th, 1849.

VII. *On the Meteorology of the Lake District of Cumberland and Westmoreland; with a continuation of the Results of Experiments on the Fall of Rain at various heights, up to* 3166 *feet above the sea level.*

By John Fletcher Miller, *F.R.S., F.R.A.S., Assoc. Inst. C.E.*
Communicated by Lieut.-Colonel Sabine, *For. Sec. R.S.*

Received March 7,—Read May 30, 1850.

Introductory Remarks.

THE Roman numerals at the head of the Tables refer to the same stations as in former years. The gauge at Round Close near Whitehaven has been discontinued, and a new station has been established on the top of Lingmell (which mountain forms the lower part of Sca Fell facing the village of Wastdale Head), so that the number of instruments is the same as in the year 1848.

During the spring, summer and autumn, the mountain gauges are emptied on the last day of each month, whatever may be the state of the weather at the time; but in the winter months, they are of course only examined when accessible, or when the contents are judged to be in a state of partial or entire liquefaction. These gauges have been frozen up since the end of October last; and at the close of the year the higher stations were inaccessible from ice and snow. On the 31st of January, 1850, the whole of the receivers were brought down into the valley, and their contents liquefied by artificial heat.

In severe winters, like the present, I find it difficult to get parties to attend to these instruments, for almost any pecuniary recompense; indeed, so great is the risk of fractured limbs, and the sacrifice of life itself, that even the hardy shepherds shrink from the task of ascending such elevated and rugged peaks as Sca Fell Pike and the Gabel, at this season; and when there is a considerable accumulation of snow on the summits, an occurrence by no means unusual, it is quite impracticable. On the 31st of January, as the person who has charge of the gauges was ascending the Gabel, with two large empty copper receivers fastened together, his foot slipped and he slided down the precipice, a distance of several hundred yards, but fortunately escaped without any material injury. The receivers parted company in the descent, and both of them were literally dashed to pieces. On the same day a shepherd met with a similar accident on Sca Fell, and the injuries he sustained were of so serious a nature as to endanger his life.

I regret that my endeavours to obtain the monthly extremes of temperature on the summit of Sca Fell Pike have hitherto failed.

The indications for 1849 are apparently so erroneous, that I cannot place any dependence upon them. The instruments are slightly inclined in the box, which is riddled with small circular holes, and it is supposed that strong currents of air passing through them have shaken the thermometers, and caused the indices to descend in the tubes. The instruments are now fastened in the case, and I hope to secure correct readings during the current year.

TABLE I.—Synopsis of the Fall of Rain in the Lake District of Cumberland and Westmoreland, in the year 1849.

No.	I.	II.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	Prevailing winds.		
	Whitehaven.										Eskdale.			Westmoreland.			Borrowdale.					
																	Seathwaite.					
1849.	High Street, 90 feet above the sea.	St. James's Church Steeple, 78 feet above the street, and 168 feet above the sea.	The Flosh, three miles south-east of Whitehaven.	Cockermouth. 126 feet above the sea.	Eassenthwaite Halls, 210 feet above the sea.	Keswick, 258 feet above the sea.	Vale of Gillerthwaite, Ennerdale, 396 feet above the sea.	Loweswater, 336 feet above the sea.	Foot of Crummock Lake, 283 feet above the sea.	Gatesgarth, 326 feet above the sea.	Centre of Vale.	Head of Vale.	Wastdale Head, 247 feet above the sea.	The How, Troutbeck, 300? feet above the sea.	Ambleside, 190 feet above the sea.	Langdale Head, 250? feet above the sea.	In Garden, 6 inches above the surface.	In Field, 18 inches above the surface.	Stonethwaite. 330 feet above the sea.	At Crummock Lake, two observations daily.	At Seathwaite, one observation daily.	At the Coast*, two observations daily.
January......	in. 5·683	in. 3·517	in. 6·82	in. 7·18	in. 7·36	in. 11·028	in. 14·20	in. 10·545	in. 12·17	in. 17·54	in. 8·97	in. 9·89	in. 21·35	in. 16·858	in. 12·80	in. 25·61	in. 24·96	in. 23·96	in. 20·02	s.w. to w.	s.w. to w.	s.w.
February ...	2·045	1·414	2·63	1·85	2·10	2·260	3·25	2·744	3·38	4·65	3·72	5·57	6·27	4·539	2·92	6·31	7·55	7·25	5·47	s.w. to w.	s.w. to w.	s.w.
March	·837	·435	1·12	1·47	1·94	1·692	3·00	2·135	2·48	3·53	2·07	3·34	4·94	1·641	1·93	4·88	5·51	5·32	3·41	s.w. to w.	s.w. to w.	s.w. & n.w.
April.........	1·488	1·104	1·60	1·91	2·74	2·358	1·80	2·209	2·91	2·69	2·48	3·03	3·55	1·837	1·72	3·22	3·88	3·78	3·01	E.	var.	E.
May	3·037	2·340	3·17	2·34	2·08	2·364	4·68	3·210	4·21	5·42	3·85	4·56	5·60	3·223	2·92	5·94	6·52	6·07	4·24	s. to s.w.	s. to s.w.	s.w.
June	1·224	·760	1·51	1·41	1·52	1·028	2·80	1·720	2·13	2·24	1·58	1·72	3·29	1·653	1·50	2·86	3·97	3·93	2·64	s.w. to w.	s.w. to w.	s.w.
July	5·478	3·622	6·34	3·91	4·04	5·104	10·07	8·147	9·53	13·94	7·21	8·83	14·29	6·350	6·56	11·01	16·64	16·60	11·18	s.w. to w.	s.w. & n.w.	n.w. var.
August	3·771	4·042	4·27	3·85	4·71	6·126	7·08	4·900	5·38	6·19	5·55	5·84	7·65	5·396	6·92	8·01	9·92	9·27	7·65	s.w. to w.	s.w. to w.	s.w.
September...	2·814	2·043	2·89	2·33	2·04	2·990	4·00	3·220	3·30	3·89	3·42	4·47	4·22	3·793	2·96	4·90	4·08	3·98	3·63	E.	E.	N.E.
October......	5·252	3·940	6·19	5·43	4·66	5·854	11·60	7·060	11·64	18·25	8·13	9·56	14·84	12·957	11·36	12·79	16·14	15·88	12·54	s. to w.	s. to s.w.	s.w.
November...	4·974	3·462	5·90	4·83	4·80	5·620	9·60	6·270	8·84	13·02	8·54	9·51	14·39	11·023	8·93	15·36	18·75	18·46	14·20	s. to s.w.	s.w. to w.	s.w.
December...	2·396	1·538	2·69	1·88	2·01	2·378	4·33	3·120	4·24	5·73	3·86	4·90	6·83	6·155	4·86	6·94	7·55	7·07	6·28	E.	var.	s.w.
1849.	38·999	28·217	45·13	38·39	40·00	48·802	76·41	55·280	70·21	97·09	59·38	71·22	107·22	75·425	65·32	107·83	125·47	121·57	94·27	s.w. to w.	s.w. to w.	s.w.
1848.	47·342	36·344	60·82	52·37	47·06	66·407	97·73	76·668	98·07	133·55	70·38	86·78	115·32	91·347	77·58	130·38	160·89	157·22	130·24	s.w.	s.w.	s.w.
1847.	42·921	30·713	47·80	42·55	44·45	58·286	80·13	66·296	82·32	106·25	58·66	74·93	96·34	78·004	......	112·95	129·24	126·80	106·21	westerly.	s.w.	s.w.
1846.	49·134	35·422	55·16	52·41	......	67·678	83·87	79·249	96·47	121·90	......	......	106·93	77·719	......	127·40	143·51					
1845.	49·207	33·489	53·00	46·93	......	62·202	76·88	69·542	87·48	124·13	......	......	108·55	76·305	......	136·00	151·87					
1844.	36·723	27·862	39·31	......	......	40·629	54·62	49·829	61·46	......	......	......	80·01	51·986								

* The prevailing wind at the coast, in 1849, is between the S. and W.S.W. points inclusive; in the Lake District it appears to have been rather more westerly, or between the S.W. and W. points inclusive; but in these confined narrow valleys, an approximation to the true direction of the under current is all that can be looked for.

TABLE II.

Wet Days.

1849.	Whitehaven.	The Flosh.	Cockermouth.	Bassenthwaite Halls.	Keswick.	Loweswater Lake.	Crummock Lake.	Eskdale.	Wastdale Head.	Ambleside.	Troutbeck.	Langdale Head.	Seathwaite.	Stonethwaite.
January ...	20	21	20	19	20	22	19	20	22	21	20	22	20	22
February...	12	14	14	12	15	15	14	13	21	12	16	16	17	15
March......	12	10	12	10	16	11	11	13	20	11	9	12	13	11
April	16	15	21	18	22	21	18	16	25	13	17	18	19	17
May	14	14	15	13	16	17	14	14	18	10	14	15	15	15
June	10	10	8	11	8	9	7	8	12	6	11	9	10	9
July.........	18	19	19	15	17	15	16	17	20	12	16	16	18	15
August ...	19	18	19	17	18	17	17	16	22	13	17	20	18	16
September..	12	10	11	13	14	11	12	11	13	9	11	13	10	12
October ...	17	17	17	18	19	18	22	17	20	16	18	20	18	18
November..	24	22	21	20	20	18	19	18	22	22	22	22	20	19
December ..	15	15	14	16	20	17	16	17	21	14	15	18	15	14
1849.	189	185	191	182	205	191	185	180	236	159	186	199	193	183
1848.	210	207	228	196	229	217	207	205	243	......	201	212	232	224
1847.	191	183	210	199	204	190	199	......	226	......	188	209	202	195
1846.	200	208	234	......	213	198	216	......	234	......	194	213	219	
1845.	193	175	212	......	195	195	202	......	211	......	180	......	211	

TABLE III.

Showing the Quantity of Rain received by the Mountain Gauges in thirteen months, between the 1st day of January 1849, and the 31st day of January 1850.

No.	XXI.	XXI.^{2}	XXII.	XXIII.	XXIV.	XXV.	XIV.	XIII.	XXVI.	XIX.
1849.	Sea Fell.		Great Gabel, 2925 feet above the sea.	Sparkling Tarn, 1900 feet above the sea.	Stye Head, 1443 feet above the sea.	Brant Rigg, about 924 feet above the sea.	The Valley.		Borrowdale.	
	The Pike, 3166 feet above the sea.	Top of Lingmell, 1778 feet above the sea.					To the west, Wastdale, 247 feet above the sea.	To the south-east, Eskdale, height unknown.	Seatollar Common, 1388 feet above the sea.	The Valley, Seathwaite, 368 feet above the sea.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
January ...	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	21·35	9·89	19·00	23·96
February...	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	6·27	5·57	Frozen.	7·25
March......	15·53	17·78	17·24	27·17	23·64	18·13	4·94	3·34	7·40	5·32
April	1·48	3·21	1·86	4·14	3·40	4·00	3·55	3·03	2·18	3·78
May	4·42	4·96	4·37	6·20	6·00	4·72	5·60	4·56	3·84	6·07
June	2·75	3·15	3·30	3·71	3·49	2·11	3·29	1·72	2·74	3·93
July.........	11·99	11·85	11·60	13·04	14·50	10·03	14·29	8·83	12·58	16·60
August ...	8·98	7·14	8·10	11·70	10·20	9·14	7·65	5·84	8·60	9·27
September..	4·54	3·30	4·10	4·40	4·87	3·70	4·22	4·47	3·98	3·98
October ...	14·00	15·50	15·00	19·48	15·23	10·93	14·84	9·56	18·30	15·88
November..	Frozen.	12·52	Frozen.	Frozen.	Frozen.	Frozen.	14·39	9·51	12·73 part frozen.	18·46
December..	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	6·83	4·90	Frozen.	7·07
1850. January ...	19·52	12·49	19·35	31·26	23·82	24·54	7·26	5·68	17·62	6·46
Inches......	83·21	91·90	84·92	121·10	105·15	87·30	114·48	76·90	108·97	128·03

TABLE IV.—For the Summer Months.

No.	XXI.	XXI.²	XXII.	XXIII.	XXIV.	XXV.	XIV.	XIII.	XXVI.	XIX.
1849.	Sca Fell.						The Valley.		Borrowdale.	
	The Pike, 3166 feet above the sea.	Top of Lingmell, 1778 feet above the sea.	Great Gabel, 2925 feet above the sea.	Sparkling Tarn, 1900 feet above the sea.	Stye Head, 1443 feet above the sea.	Brant Rigg, about 924 feet above the sea.	To the west, Wastdale*.	To the south-east, Eskdale.	Seatollar Common, 1388 feet above the sea.	The Valley, Seathwaite, 368 feet above the sea.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
May	4·42	4·96	4·37	6·20	6·00	4·72	5·60	4·56	3·84	6·07
June	2·75	3·15	3·30	3·71	3·49	2·11	3·29	1·72	2·74	3·93
July	11·99	11·85	11·60	13·04	14·50	10·03	14·29	8·83	12·58	16·60
August ...	8·98	7·14	8·10	11·70	10·20	9·14	7·65	5·84	8·60	9·27
September..	4·54	3·30	4·10	4·40	4·87	3·70	4·22	4·47	3·98	3·98
October ...	14·00	15·50	15·00	19·48	15·23	10·93	14·84	9·56	18·30	15·88
Inches......	46·68	45·90	46·47	58·53	54·29	40·63	49·89	34·98	50·04	55·73

TABLE V.—For the Winter Months.

1849.	Sca Fell.		Great Gabel.	Sparkling Tarn.	Stye Head†.	Brant Rigg.	The Valley.		Borrowdale.	
	The Pike.	Lingmell.					To the west, Wastdale.	To the south-east, Eskdale.	Seatollar Common.	Valley. Seathwaite.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
January ...	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	21·35	9·89	19·00	23·96
February...	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	6·27	5·57	Frozen.	7·25
March ...	15·53	17·78	17·24	27·17	23·64	18·13	4·94	3·34	7·40	5·32
April	1·48	3·21	1·86	4·14	3·40	4·00	3·55	3·03	2·18	3·78
November..	Frozen.	12·52‡	Frozen.	Frozen.	Frozen.	Frozen.	14·39	9·51	12·73 part frozen.	18·46
December..	Frozen.	Frozen§.	Frozen.	Frozen.	Frozen.	Frozen.	6·83	4·90	Frozen.	7·07
1850. January ...	19·52	12·49	19·35	31·26	23·82	24·54	7·26	5·68	17·62	6·46
Inches......	36·53	46·00	38·45	62·57	50·86	46·67	64·59	41·92	58·93	72·30

* Sca Fell is situated between the heads of the valleys Wastdale and Eskdale.

† There is a marked deficiency at this station in the winter months, whilst in the summer months the *proportion* is above the average at this altitude.

‡ The receiver was brought into the valley and its frozen contents melted.

§ January 31, 1850. The whole of the receivers were brought down into the valley and their contents liquefied.

TABLE VI.—Temperature at Seathwaite in Borrowdale, in 1849.

1849.	Absolute.		Mean of Max.	Mean of Min.	Approximate mean Temperature.	Mean at 9 A.M.	On Grass.				Prevailing winds.
	Max.	Min.					Min.	Mean.	Radiation.		
									Max.	Mean.	
January	50°	16°	40°·95	32°·82	36°·88	36°·91	5°	29°·20	13°·2	4°·16	s.w. to w.
February	49·8	26	44·85	37·46	41·15	41·07	20	34·77	7·5	3·08	s.w. to w.
March............	52	26	46·35	36·51	41·43	41·00	21	32·74	12·0	3·54	s.w. to w.
April	60	26	45·98	36·45	41·21	40·71	17·3	32·09	10	4·36	Var.
May	69	36	58·03	45·32	51·67	50·05	27	37·73	15	7·59	s. to s.w.
June	71	40	61·40	48·50	54·95	54·40	28	39·41	15	9·08	s.w. to w.
July	76·3	46	63·11	53·05	58·08	56·79	33	44·85	17	8·19	s.w. and N.w.
August	71·5	44	61·99	53·32	57·65	57·00	32	46·72	13	6·60	s.w. to w.
September	71	39	59·64	46·91	53·27	52·75	26	37·26	15·5	10·03	E.
October	62	30	50·38	40·29	45·33	44·59	21	33·88	11·5	6·41	s. to s.w.
November	59	25	48·35	38·30	43·32	42·10	15	32·16	10	6·13	s.w. to w.
December	50	20	40·35	32·85	36·60	36·80	13	27·25	10	5·60	Var.
1849.	61·8	31·1	51·78	41·81	46·79	46·18	21·5	35·67	12·4	6·23	s.w. to w.
1848.	62·4	30·5	52·15	42·06	47·10	46·76	20·5	35·18	12·9	6·91	s.w.
1847.	62·7	29·9	52·89	42·04	47·46	47·21	......	......	......	......	s.w.
At Whitehaven.											
1849.	62·3	33·7	53·24	44·15	48·69	......	18·8	35·05	18·4	9·09	s.w.
1848.	62·9	32·6	53·77	43·79	48·78	......	20·2	35·73	15·9	8·06	s.w.
1847.	62·2	33·7	53·85	43·50	48·68	......	21·4	36·05	15·1	7·45	s.w.

Remarks.

As regards the fall of rain, the years 1848 and 1849 have been of a totally opposite character; for, whilst 1848 was by much the wettest, the year 1849 is the driest which has occurred since these experiments were begun in the summer of 1844. In 1849, the vales of Seathwaite, Langdale, Gatesgarth, Buttermere and Loweswater, have received less rain than the average of the four previous years by 20·90 inches, 18·85 inches, 24·36 inches, 20·88 inches, and 17·65 inches respectively; and 35·42 inches, 22·55 inches, 36·46 inches, 27·86 inches and 21·38 inches respectively, less than in the excessively wet year 1848.

It is a remarkable fact, that whilst from one-fourth to one-seventh less rain than usual has descended in the valleys generally, Wastdale Head has obtained nearly half an inch *more* than its average quantity*. It will be observed that the south-west wind has prevailed to an unusual extent in the past year. The south-west is the predominant wind in nine months of 1849, and in the other three months it has been the same current which brought the rain. Now, whereas the valleys in general open out towards the north-west, the Vale of Wastdale directly faces the south-west, and a current from that quarter flows freely up the valley without any intervening object to obstruct its progress; so that an extraordinary prevalence of south-westerly winds might be expected to increase the amount of rain at Wastdale, and to diminish it in the other valleys; and *vice versâ,* with a long continuance of north-westerly winds. Troutbeck, which is similarly situated to Wastdale, has only received about 5 inches, or one-sixteenth less than the average quantity.

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* The rain was read off and recorded by the same registrar as in former years, and there can be no doubt of the correctness of the returns. That this instrument must have been attended to with the greatest regularity, is evident from the fact of there having been 236 measurements of rain at Wastdale Head in 1849, a number considerably exceeding the wet days at any other station, so that the smallest appreciable portions must have been recorded.

The wet days at Wastdale are generally about sixteen more than at Seathwaite, the wettest of the stations; but in 1849, they are forty-three in excess, and thirty-one more than have been recorded in any other part of the Lake District.

This may be accounted for from the fact, that the mountains surrounding the Head of Wastdale are both the highest and the nearest to the sea; their elevated peaks attract the clouds, and occasionally deprive them of the *whole* of their water; and such appears to be more particularly the case in dry seasons and periods. Hence Wastdale is visited with many showers which never reach the more inland valleys. The increase in the annual depth of rain from this cause is, however, very trifling.

Gatesgarth, which usually obtains about one-fifth more rain than Wastdale, in 1849 has received nearly 10 inches *less*; and in the latter half of the exceedingly dry year 1844, I find that the excess was also in favour of Wastdale.

These abnormal results are evidently the effect of the position or bearing of the respective valleys in regard to the prevalent wind. Wastdale may be said to receive the south-west wind with open arms; but, at Gatesgarth, it traverses the narrow valley and its mountain ridges nearly at right angles.

The wettest days in 1849 were the 24th of January and the 24th of October; on the former there fell 4·30 inches at Seathwaite, and on the latter 4·37 inches at Wastdale Head. In four days, between the 22nd and 25th of October, the fall at Wastdale was 9·94 inches, and at Seathwaite 10·79 inches.

The average depth of rain in the different valleys throughout the Lake District during the last five years, is as under:—

	inches.
High Street, Whitehaven	45·52
St. James's Church Steeple, Whitehaven	32·84
The Flosh, three miles south-east of Whitehaven	52·38
Cockermouth	46·53
Bassenthwaite (three years)	43·83
Keswick	60·67
Gillerthwaite, Ennerdale	83·00
Loweswater Lake	69·40
Crummock Lake	86·90
Gatesgarth	116·58
Eskdale, middle of vale (two years)	64·88
Eskdale, head of vale (two years)	79·00

	inches.
Wastdale Head	106·87
Ambleside (two years)	71·45
The How, Troutbeck, Westmoreland	79·76
Langdale Head, Westmoreland	122·91
Seathwaite, Borrowdale	142·19
Stonethwaite, Borrowdale (two years)	112·25

In my last paper I stated that the inhabitants of the Lake District valleys enjoyed a milder and more equable climate than the residents in the open country, and particularly in the winter months. This remark is confirmed by the thermometrical results of the present winter, as will be seen by inspecting the following comparative table:—

1849.	Seathwaite.				The Flosh, Whitehaven.				Cockermouth*.	
	Mean of max.	Mean of min.	Mean temperature.	Absolute min.	Mean of max.	Mean of min.	Mean temperature.	Absolute min.	Mean of min.	Absolute min.
November ...	48°·35	38°·30	43°·32	25°	45°·56	35°·50	40°·53	20°	37°·73	22°
December ...	40·35	32·85	36·60	20	39·39	29·32	34·35	18	31·55	20
1850. January	36·88	28·42	32·65	19	34·45	25·48	29·96	14	27·16	14
Means.........	41·86	33·19	37·52	19	39·80	30·10	34·94	14	32·14	14

Seathwaite is about fourteen miles inland. The Flosh is three miles south-east of Whitehaven, and the same distance from the sea in the direction of the mountains. Cockermouth is about six miles from the nearest part of the coast, and eight miles nearer to the sea than Seathwaite. Now places situated on the west coast of England are generally warmer than more inland localities; and, were the whole country a vast plain, the temperature would probably be found to diminish with some regularity in proportion to the distance from the western ocean; but from the operation of causes referred to in a former paper, the mountain district of Cumberland is an exception to the general fact.

At Seathwaite, the thermometer on the grass has been below the freezing-point in every month of 1849, except July, when it was 1° above it; and the mean of the whole absolute minima is 10°·5 below the point of congelation.

In January, this thermometer was at or below 32° on seventeen nights; in February, on ten nights; in March, on fourteen nights; in April, on fifteen nights; in May, on eight nights; in June, on six nights; in July, on 0 nights; in August, on two nights; in September, on nine; in October, on sixteen; in November, on fifteen; and in December, on twenty-four nights. The thermometer used for showing the temperature at the surface is a common RUTHERFORD; had a more delicate instrument been employed for the purpose, the mean of the terrestrial radiation would probably have been about a degree higher than the result shown in the table. A naked thermometer under pretty similar circumstances, at Whitehaven, has been below 32° in every month of last year, viz. in January, on nineteen; in February, on fourteen; in March, on thirteen; in April, on eighteen; in May, on eleven; in June, on eight; in July, on one; in August, on two; in September, on five; in October, on sixteen; in November, on thirteen; and in December, on twenty-four nights. The mean of the whole minima is 18°·8.

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* The maximum thermometer was not recorded at Cockermouth in 1849.

The Mountain Gauges.—On the whole, the results are similar to those of the three preceding years, but, as might be looked for in a dry year like the past, the quantities deposited at the various stations are more nearly equal than usual; in other words, the differences are not so great or striking as obtain in either wet or average periods.

A trifling change in the position of the gauge on Seatollar Common in Borrowdale, has led to some rather startling results, which promise in time to guide us to the proximate cause of the enormous excess of rain in this valley over every other in the Lake country. It is expected that this gauge (Seatollar, supposed to be 1300 feet above the sea), which has hitherto obtained about one-fifth *less*, will in future impound quite as much, or even more rain than the noted vale of Borrowdale.

The year 1849 has not enabled me to add any new fact of importance to those already communicated to the Royal Society in reference to this part of the inquiry; and as the past annual period has evidently been of an anomalous character, I think it better to avoid drawing any inference or conclusion from the results which it has afforded. I am the more inclined to defer deductions to a future time, from the circumstance of my having been compelled to estimate the heights of some of the mountain stations, which have never been measured; and because I hope to have an opportunity of taking the altitudes myself in the course of the ensuing summer. These scanty remarks must therefore be regarded as a mere supplement to the papers previously printed in the Philosophical Transactions.

The Observatory, Whitehaven,
February 11, 1850.

VIII. *On the Structure of the Membrana Tympani in the Human Ear.* *By* JOSEPH TOYNBEE, *F.R.S., Fellow of the Royal College of Surgeons of England, Aural Surgeon to St. Mary's Hospital, and Consulting Surgeon to the St. George's and St. James's General Dispensary.*

Received June 19,—Read June 20, 1850.

IN conducting researches into the pathological condition of the organ of hearing, I have been impressed with the necessity of ascertaining, with as much precision as possible, the intimate structure of the various tissues entering into its composition. The results to which investigations undertaken with this latter object in view have led me, in reference to the structure of the membrana tympani, it is the purpose of the present paper to detail. It will be observed that the conclusions at which I have arrived, differ materially in various important particulars from those of previous investigators.

Examined from the exterior, inwards the membrana tympani consists of the following layers:—

1. The epidermis.
2. The proper fibrous layer, composed of—
    - *a.* The lamina of radiating fibres.
    - *b.* The lamina of circular fibres.
3. The mucous membrane (Plate III. fig. 1).

1. The *epidermis* is a thin layer covering the outer surface of the radiating fibrous lamina; it is continuous with the epidermis of the external meatus, and when subjected to the process of maceration it can be removed in the form of a small blind pouch, which presents, as it were, a cast of the meatus and of the external surface of the membrana tympani. When floating in water the pouch assumes the form it had when in contact with other tissues, and its internal extremity is convex, corresponding with the external concavity of the membrana tympani (fig. 2). The layer of epidermis forming the outermost coat of the membrana tympani is thin, and in the living subject so transparent that the radiating fibrous layer is distinctly seen through its substance: its outer surface is very smooth and capable of reflecting light: this layer presents no appearance of an orifice.

2. The *proper fibrous layer* of the membrana tympani can be easily separated into two laminæ, which, on account of the direction of their component fibres, may be called the radiating fibrous and the circular fibrous laminæ. Previous to entering upon an examination of these structures, it is desirable to cite the opinions which eminent anatomists have entertained on the subject.

In the Croonian Lecture, published in the nineteenth volume of the Philosophical Transactions, Sir Everard Home advanced the opinion that the membrana tympani in the human subject was muscular. His words are, "When viewed in a microscope magnifying twenty-three times, the muscular fibres are beautifully conspicuous, and appear uniformly the same throughout the whole surface. There being no central tendon as in the diaphragm, the muscular fibres appear only to form the internal layer of the membrane, and are most distinctly seen when viewed on that side[*]." The use of this radiated muscle, Sir Everard Home states, is "to give those different degrees of tension to the membrane, which empower it to correspond with the variety of external tremors[†]." Since the first publication of this opinion as to the muscularity of the membrana tympani, anatomists have generally conceded that it is fibrous, but they have widely differed as to its composition. According to Mr. Quain and Dr. Sharpey, "it is made up of fine closely arranged fibres, the greater number of which radiate from near the centre to the circumference; but within these are circular fibres which are more scattered and indistinct, except close to the margin of the membrane, where they form a dense, almost cartilaginous ring[‡]." Mr. Wharton Jones writes, "The proper membrane can be divided into two layers, an outer thin one, consisting of radiating fibres, and an inner thicker layer, which is less distinctly fibrous, though when torn it does indicate a fibrous disposition, and that in a direction opposite to the former..... The fibres which cross the radiating ones are also more aggregated at the centre. They run parallel with the handle of the malleus and turn round its extremity. At the circumference of the proper membrane there is a thick firm ligamentous or cartilaginous ring, which is fixed in the groove of the bone. The ligamentous ring appears to be formed by an aggregation of the circular fibres interwoven with the peripheral extremities of the radiating ones[§]."

By careful dissection the fibrous layers of the membrana tympani may be separated into two distinct laminæ, the fibres of which have no communication with each other. The external layer may be called the *radiate fibrous lamina*, on account of its fibres radiating from the malleus to be attached to the cartilaginous ring, and the internal the *circular fibrous lamina*. The radiate layer is the thicker and stronger. So readily may the two layers be separated from each other, that they are detached with greater facility than that with which the circular layer can be removed from the mucous membrane.

a. *The Radiate Fibrous Lamina.*

If the whole of the membrana tympani be carefully removed, there will be observed at its circumference a white dense ring, apparently cartilaginous, which is received into the osseous groove of the temporal bone appropriated to it. It will be remembered however that this groove occupies only about five-sixths of the circumference of the inner extremity of the meatus, the upper sixth being smooth instead of grooved.

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[*] *Loc. cit.*, p. 5.

[†] P. 11.

[‡] Elements of Anatomy, fifth edition, 1848, vol. ii. p. 932.

[§] Cyclopædia of Anatomy and Physiology, vol. ii. p. 545.

The cartilaginous ring at the upper part is attached to the malleus, the anterior extremity being inserted into the anterior part of the cervix of this bone, and the posterior extremity into its posterior part; the outer surface of this ring has attached to it the periosteum, lining the external meatus (fig. 3). If the radiate lamina be examined with a magnifying power of ten or twelve diameters, fibres will be observed whose peripheries are attached to the cartilaginous ring, and their other extremities to the malleus. The uppermost of these fibres, however, must be excepted from the observation just made, for instead of passing from the superior part of the cartilaginous ring to the malleus, they take their course in front of the processus brevis and form a distinct layer of membrane covering its outer surface (fig. 3). The disposition of this portion of the radiating fibrous lamina is interesting alike to the anatomist and to the surgeon, for it is observed to be continuous with the periosteal lining of the upper part of the external meatus. Mr. Shrapnell, perceiving that this portion of the membrana tympani was not so tense as the rest, considered it to be a distinct structure, and named it the "membrana flaccida*."

Directly below the processus brevis of the malleus the radiating fibres are attached to the ridge occupying the external surface of the bone, but at this part the fibres from each half of the membrana tympani are inserted so near to each other that no portion of the malleus is visible when viewed exteriorly; towards the inferior extremity of the long process, however, the fibres are attached to the sides and not to the anterior surface, and thus a small portion of the external surface of the long process at its inferior part is left bare and is in contact with the epidermoid layer, as may be distinctly seen in the healthy living ear by means of the speculum auris and a magnifying lens. The fibres extending from the malleus and forming the posterior segment of the membrane, are one-fourth longer than those forming the anterior segment. The thickest part of this layer is that which surrounds the extremity of the long process of the malleus, and the most attenuated is that which lies between the posterior margin of the long process of the malleus and the circumference of the membrana tympani†.

Structure of the Radiate Lamina.

The fibres composing the radiate lamina, when examined in a fresh state by the microscope, are translucent, and with the exception of a few transparent granules, present no peculiarity of structure; the longitudinal parallel wavy lines, characteristic of ordinary fibrous membranes, are absent. These fibres are flat, and vary from a 4000th to a 5000th part of an inch in breadth (fig. 5). In passing from the circular cartilage to the malleus these fibres interlace with each other, from whence originates the peculiar diamond-shaped markings observable on the outer surface of the membrane (fig. 6). When treated with acetic acid this lamina becomes opake, and sometimes elongated oval nuclei are observed, the long axes of which correspond with the course of the fibres (fig. 7). These nuclei are by no means invariably to be detected, and in several specimens they were not apparent on the application of the acid. In no instance was an oval nucleus visible in an isolated fibre.

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* Medical Gazette, vol. x.

† The blood-vessels ramifying in the upper part of the membranous lining of the external meatus are freely continuous with those of the membrana tympani. These blood-vessels are connected by cellular tissue, and the two together often form a distinct layer of membrane covering the outer surface of the upper part of the external radiate fibrous lamina (fig. 4). See Appendix.

The *circular white band* at the circumference of the radiate fibres consists of a firm mass of tissue, which is slightly elastic. It presents an indistinct appearance of fibres intermixed with oval-shaped nuclei. Upon the application of acetic acid this structure loses its white aspect, becomes translucent, and discloses a greater number of the oval nuclei (fig. 8).

b. *The Circular Fibrous Lamina.*

This membrane is attached to the radiating fibres by fine cellular tissue, and, as previously stated, the two structures can be separated with facility; the fibres of each lamina are quite distinct and never intermingle. The circular lamina consists, as its name implies, of circular fibres; they are firm and strong at its circumference, but towards the centre they are so attenuated as to be detected only by considerable care. The strong fibres at the circumference of the layer form a complete circle, and are attached to each side of the body of the malleus and to the sides of the upper third of the *processus longus* (fig. 9). When carefully examined by a magnifying power of thirty to forty diameters, these circular fibres are observed to be intersected by others of an extremely delicate character; these delicate fibres are more numerous towards the central part of the lamina, where they are so intimately blended with the circular fibres that the latter are not easily distinguished (fig. 10). The central thin portion of the circular lamina is not attached to the malleus, but the fibres from each side are continuous, and they form a membranous layer composed of a series of concentric fibrous circles. The outer surface of this central portion of the lamina is in contact with the inner surface of the lower half of the long process of the malleus, to which it is adherent by loose cellular tissue. The circular fibrous lamina is entirely unconnected with the cartilaginous ring into which the radiating fibres are inserted, but it is continuous with the periosteal lining of the tympanic cavity, of which it may be considered a modification. When the lamina of circular fibres is detached from that of the radiating fibres, it will be found to be slightly concave externally, though not to the same extent as the outer layer. In its separate condition it becomes rather less concave than when it was applied to the inner surface of the radiating fibres, and when its central portion is pressed inwards so as to increase its concavity, its inherent elasticity causes it quickly to resume its former shape, resembling that of a saucer. If the two layers be detached from each other and placed side by side, the greater degree of concavity externally of the radiating fibrous layer is very perceptible.

Structure of the Circular Lamina.

When highly magnified, the fibres composing the circular lamina are found to be smaller than those constituting the radiate fibrous layer; they vary in size from the 6000th to 10,000th of an inch in breadth. The outer fibres run parallel with each other, and do not interlace so much as the radiating fibres; they are diaphanous, and do not present any wavy longitudinal lines (fig. 11). When acetic acid is applied the fibres enlarge and assume a certain degree of opacity, and in some instances this lamina also has presented distinct oval nuclei, elongated in the direction of the fibres (fig. 12). Like the radiate lamina, the separate fibres were never observed to reveal the existence of nuclei, and as a general rule their presence in the tissue is not detected.

It is often not easy to decide whether a structure is muscular, and doubts may arise as to the real nature of the two fibrous laminæ of the membrana tympani. My own researches do not seem to favour the view of that membrane being a contractile tissue.

The facts which seem to militate against the idea of its being muscular are,—

1st. The absence of distinct nuclei in the fibres.

2nd. Their great denseness and hardness, their firm and unyielding structure, they being so strong that it is with some difficulty they can be torn across.

The *mucous membrane* forming the inner layer of the membrana tympani is in the healthy ear so extremely thin that its presence is with difficulty detected; by careful dissection however it can nevertheless be removed entire from the inner surface of the circular fibres, to which it is connected with considerable firmness by fine cellular tissue.

It will now be evident that of all the laminæ which constitute the membrana tympani not one is proper to the organ, all of them being directly continuous with other structures, of which they appear to be modifications*. Thus:—

1st. The *epidermis* is continuous with that lining the external meatus.

2nd. The *radiate fibrous lamina* is a prolongation of the periosteal lining of the external meatus.

3rd. The *circular fibrous lamina* is a prolongation of the periosteum of the tympanum.

4th. The layer of *mucous membrane* forms part of the lining of the tympanic cavity (fig. 13).

Previous to considering the functions of the fibrous laminæ of the membrana tympani, it is desirable to advert to another point in the structure and relations of this organ. It has been already stated that the membrana tympani is attached at its circumference to the temporal bone, and at its central part to the malleus. The latter bone is so suspended by means of the processus gracilis and the short process of the incus*, that the long process can move inwards towards the tympanic cavity, and outwards towards the meatus (fig. 14). It must be evident, therefore, that in order to prevent the concave membrana tympani, with the above attachments, from remaining in a state of relaxation, either the tensor tympani muscle must be in a state of continual contraction, or some other provision must exist for retaining the membrana tympani in the moderately tense condition fitting it to receive the sonorous undulations. The provision which actually exists, and which, so far as I am aware, has hitherto escaped the attention of anatomists, is the *tensor ligament of the membrana tympani.*

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* See Appendix.

The ligament in question is about three-fourths of a line in length, and it is attached internally to the cochleariform process, and externally to that part of the inner surface of the malleus where the long process joins the neck (fig. 15). In the interior of this ligament, which presents a tubular shape, is placed the tendon of the tensor tympani muscle. It is thin anteriorly, where it consists of very delicate fibres, but the remainder is thick and dense, being composed of firm ligamentous tissue. So long as this ligament remains entire and the membrana tympani uninjured, the latter structure retains its natural degree of concavity and tenseness; but upon the ligament being cut through, or upon a solution of continuity being effected as the result of disease, the membrana tympani becomes very flaccid, even though the tendon of the tensor tympani muscle remains entire. In a preparation, when the tensor tympani muscle is pulled†, the membrana tympani is rendered very tense, and the tensor tympani ligament is relaxed; but immediately that the muscle is relaxed the membrana tympani is observed to return to its usual state, and the ligament is again rendered tense.

On the Functions of the Fibrous Laminæ of the Membrana Tympani.

It is obvious that one use of the fibrous laminæ of the membrana tympani is to present a firm but delicate membranous septum for the reception of sonorous undulations. The arrangement of the two sets of fibres at right angles to each other has the effect of imparting great strength to the membrane, while it preserves its extreme delicacy and tenuity. It has been stated that there is no evidence to prove that the fibres, of which the membrana tympani is composed, possess in themselves any contractile power; neither do the component fibres of the laminæ appear to evince more than an extremely slight degree of elasticity. An examination however of the structure after death shows that it has an inherent power of returning to its natural state of tension after being unusually distended. Thus, if the membrana tympani be exposed without interfering with its natural state of tension, and the canal containing the tensor tympani muscle be laid open, so that that muscle can be drawn towards its origin, the external concavity of the membrana tympani can be increased till it becomes very tense, but as soon as the muscle is let go the membrana tympani will be observed to resume its former condition. This action is explainable partly by the slight elasticity of the circular cartilaginous band, into which the peripheral extremities of the radiating fibres are inserted, and partly by the slight elasticity of these fibres themselves, but more especially by the peculiar arrangement of the circular fibrous lamina, which it will be remembered has always a tendency, when left to itself, to assume a more shallow form. Thus, when the membrane is rendered very concave, the circular fibres are slightly separated from each other; but when the extra tension ceases, the fibres intersecting the circular ones aid in drawing the latter together again.

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* The short process of the incus is attached to the margin of the mastoid cells by ligamentous fibres, which allow of a lateral motion only.

† The tensor tympani muscle has an attachment which appears not to have been hitherto noticed. The tendon is generally described as passing backwards from the muscle, and then turning outwards over the cochleariform process to be attached to the malleus; but previously to changing its direction this tendon is very firmly attached by strong ligamentous tissue to the posterior extremity of the groove of the tensor tympani muscle (fig. 16). When the muscle contracts, these ligamentous fibres are put on the stretch, and the portion of the tendon that passes to the malleus being also stretched, the malleus is drawn in, and the membrana tympani rendered tense; but with whatever degree of force the muscle may afterwards be pulled, the membrana tympani itself is not rendered more tense in the slightest degree, the whole strain being on the above-described ligamentous fibres attached to the groove. If these fibres are cut through and the muscle be tightly drawn, the membrana tympani is ruptured.

The disposition of the central part of the circular lamina also assists it in the function of bringing back the membrana tympani to its natural state after tension by the tensor tympani muscle. It has been stated that the middle part of these circular fibres, instead of being attached to the handle of the malleus, are applied against its inner surface, and thus the membrane is rendered tense by the pressure of the long process of the malleus against its outer surface during the action of the tensor tympani muscle, and when this muscle ceases to act the central part of the circular layer of fibres reacts on the malleus, and constrains it to resume its usual position. Besides the office of bringing the membrana tympani to its natural state after the action of the tensor tympani muscle, the circular fibrous layer would appear to be always acting as an antagonist to the tensor tympani ligament, and by the continued action of these two tissues, the one drawing it inwards, the other outwards, the membrana tympani is kept in a state adapted to receive all the ordinary sonorous undulations, independent of the exercise of any muscular power.

EXPLANATION OF THE FIGURES.

PLATE III.

Fig. 1. The epidermoid layer having been removed by maceration, the two fibrous laminæ and the mucous membrane are seen partially separated by dissection. (Natural size.)

Fig. 2. The tubular cul-de-sac formed by the epidermis lining the external meatus; the inner extremity corresponding with the membrana tympani is convex. (Natural size.)

Fig. 3. The radiate fibrous lamina of the membrana tympani; the fibres of which it is composed extend between the cartilaginous ring and the malleus, with the exception of the uppermost fibres, which are not inserted into the malleus. (Slightly magnified.)

Fig. 4. The external surface of the membrana tympani, the epidermoid layer having been removed; the upper part of the membranous meatus is seen to be continuous with a membrane covering the upper and outer surface of the radiate fibrous lamina. [This membrane is the dermoid lamina of the membrana tympani; it is described in the Appendix to the paper as covering the whole of the outer surface of the radiating fibrous lamina.]

Fig. 5. The fibres composing the radiate fibrous lamina. (Magnified about 300 diameters.)

Fig. 6. The radiate fibrous lamina, external surface displaying the peculiar markings caused by the interlacement of the fibres. (Magnified about 300 diameters.)

Fig. 7. The radiate fibrous lamina after having been treated with acetic acid.

Fig. 8. The circular cartilaginous band after having been treated with acetic acid.

Fig. 9. The external surface of the circular fibrous lamina; the fibres being attached to the processus longus of the malleus. (Slightly magnified.)

Fig. 10. The internal surface of the circular fibrous lamina; the long process of the malleus is seen through the translucent central part. (Slightly magnified.)

Fig. 11. The fibres composing the circular fibrous lamina. (Magnified about 300 diameters.)

Fig. 12. The circular fibrous lamina after being treated with acetic acid.

Fig. 13. The radiate fibrous lamina, the circular fibrous lamina and the mucous membrane of the membrana tympani seen to be continuous with other structures. (Slightly magnified.)

Fig. 14. The attachment of the incus and malleus, illustrative of the movements of the incus, malleus and membrana tympani.

Fig. 15. The attachments of the tensor tympani ligament; the tendon of the tensor tympani muscle is drawn upwards so as to expose the ligament.

Fig. 16. The insertion of the tensor tympani muscle and its attachment by strong ligamentous fibres to the inner part of the base of the cochleariform process.

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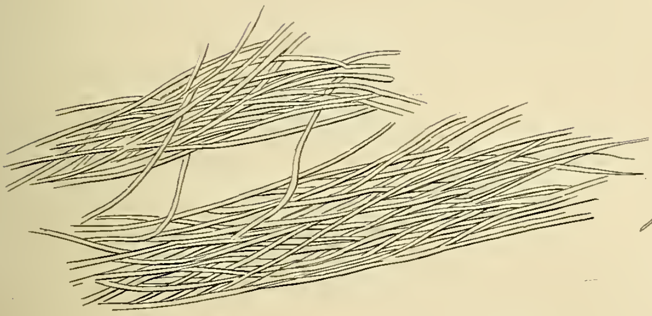

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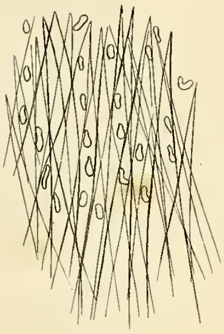

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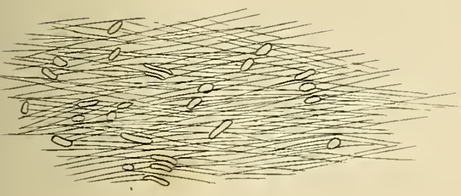

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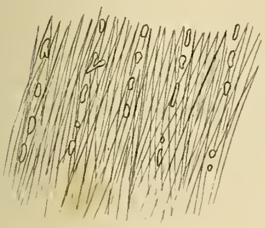

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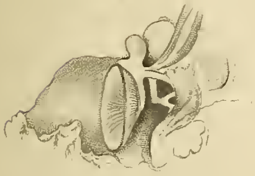

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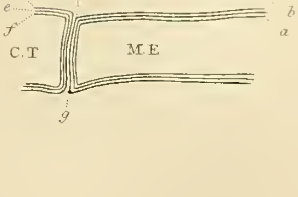

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BRITISH MUSEUM
NATURAL HISTORY.

Appendix to a Paper "On the Structure of the Membrana Tympani in the Human Ear."

By Joseph Toynbee, *F.R.S., Fellow of the Royal College of Surgeons of England, Aural Surgeon to St. Mary's Hospital, and Consulting Surgeon to the St. George's and St. James's General Dispensary.*

In a note at p. 161 of the above paper, I have stated that "the blood-vessels ramifying in the upper part of the membranous lining of the external meatus are freely continuous with those of the *membrana tympani*. These blood-vessels are connected by cellular tissue, and the two together often form a distinct layer of membrane, covering the outer surface of the upper part of the radiate fibrous lamina (fig. 4)." Since writing the above lines I have had opportunities of making several careful dissections of the membrane alluded to, and the result of these dissections is to demonstrate that between the epidermoid and radiating fibrous layers of the *membrana tympani*, there is a distinct and complete lamina of membrane which is continuous with the dermoid layer of the meatus. The presence of this membrane, to which, on account of its structure and functions, I have given the name of *dermoid layer*, is best demonstrated by carefully dissecting under water the membranous meatus from the upper surface of the osseous tube as far as the attachment of the membrani tympani; at this point the periosteum of the meatus is seen to become continuous with the radiate fibrous lamina; this being cut through, the dermoid layer is seen passing down over the outer surface of the radiate fibres, and separating them from the epidermis. If the upper portion of this layer be drawn gently downwards by one hand, by means of a fine needle in the other, the delicate cellular tissue connecting it to the fibrous lamina can be broken up and it may be removed entire. The presence of the dermoid lamina may also be shown by the introduction of a fine bristle between it and the radiating fibrous layer, at the superior part of the *membrana tympani*, and then by passing it down the cellular tissue is lacerated.

In a healthy state, when uninjected by blood or by artificial means, the dermoid lamina is thin and transparent; examined by the microscope its structure is found to resemble areolar tissue. When injected, this membrane is observed to have numerous blood-vessels ramifying through it, and they form an elaborate plexus; when these vessels are enlarged, they give the red appearance to the surface of the *membrana tympani* which is so frequently met with during life. It is upon the supply of nerves to this membrane that the exquisite sensibility of the *membrana tympani* depends.

A knowledge of the existence of the membrane here described is of interest to the anatomist, who recognizes in it the secreting organ of the epidermoid layer of the *membrana tympani*; and to the surgeon, who by its presence is able to understand phenomena occurring in certain diseases of the ear which have been hitherto incomprehensible to him. Figure 17 is illustrative of the structure of the *membrana tympani*, and it shows that the six layers of which it is composed are continuous with adjacent tissues.

I may state in conclusion, that the opinion of the non-muscularity of the fibrous laminæ of the *membrana tympani* advanced in the above paper, has been confirmed by Dr. Harrison of Dublin, in his dissection of the *membrana tympani* of the Elephant; he says, "I see no evidence of the muscular structure of the membrana tympani, so accurately described by Sir Everard Home in the Philosophical Transactions, and mentioned by subsequent writers, who seem to have adopted his opinions rather than to have examined the organ for themselves*."

Explanation of figure 17, showing the six Laminæ composing the Membrana Tympani.

A vertical section from without inwards of the meatus externus, membrana tympani and cavitas tympani.

M. E. Section of the meatus externus.
C. T. Section of the cavitas tympani.
M. T. Section of the membrana tympani.
a. The epidermis lining the meatus externus.
b. The dermoid layer of the meatus externus.
c. The periosteum of the meatus externus.
d. The periosteum of the tympanic cavity.
e. The mucous membrane of the tympanic cavity.
f. The epithelium of the tympanic cavity.
g. The circular fibro-cartilage of the membrana tympani.

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* Anatomical Observations on some Parts of the Elephant, by Robert Harrison, M.D., Professor of Anatomy, Trinity College, Dublin. Proceedings of the Royal Irish Society, vol. iii.

18 *Savile Row.*

IX. *On the Impregnation of the Ovum in the Amphibia.* (*First Series.*)

By George Newport, *F.R.S., F.L.S. &c.*

Received June 20,—Read June 20, 1850.

THE communication which I have now the honour to present to the Royal Society is a portion of a series of investigations on the Development of the Embryo on which I have been for some years engaged, and which was commenced in a paper on the Development of the Myriapoda, that was honoured with a place in the Philosophical Transactions for 1841. I now propose to give the results of my observations on the Amphibia, reserving to a future early occasion the continuation of those on the Invertebrata commenced in the paper alluded to.

The Amphibia, of all the vertebrated animals, afford to us the readiest means of investigating the difficult subject of Impregnation by actual experiment, and it is only, perhaps, by combining experiment with careful observations on the physical conditions that affect the development of the germ, and comparing these with the facts of the natural history and instincts of the species, that we may hope, ultimately, to obtain some further insight into this one of Nature's most hidden secrets.

I shall endeavour, therefore, in this communication, to show the condition of the ovum in the Amphibia through its earliest changes, and also before and immediately after impregnation, and to detail experiments made with a view to learn by what means its fecundation is effected;—and in a future communication I propose to trace the development of the embryo from the time of fecundation to that of its liberation from the ovum, in the two chief divisions of the class,—the tailless and the tailed Amphibia. The subjects thus naturally form two series—Impregnation and Development.

IMPREGNATION OF THE OVUM.

The history of what we can now prove to be the agent of impregnation, the spermatozoon, deserves to be especially noticed. Although great attention has been paid by physiologists during the last thirty years to almost every point of inquiry connected with the production and physical composition of the seminal fluid of animals, and its relation to the fecundation of the ovum, we have remained to the present time without any acknowledged proof either of the part which the different constituents of this fluid take in impregnation, or of the mode in which it effects impregnation. This perhaps is little to be wondered at when we remember how many years elapsed before the great discovery of Ham and Leewenhoek of the existence of moving bodies in the fluid, as part of its normal composition, was admitted. It is now one hundred and eighty-three years since Leewenhoek communicated the important discovery of these bodies to the Royal Society[*], and regarded them as in some way essential to the fecundation of the ova; although his conjecture that they became the future embryos was erroneous. Eighty-five years afterwards, Dr. PARSONS, Foreign Secretary of the Royal Society, believed it to be "extreme nonsense to imagine that the insignificant animals called *spermatic animals* can contribute anything towards propagation," &c.[†], and it was not until the publication of the observations of LEDERMÜLLER[‡], a few years after that, that the production of spermatozoa, as part of the fluid, began to be admitted. Dr. HILL, in the notes to his English translation of SWAMMERDAM's Biblia Naturæ[§], two years later, mentioned them as abundant in the Frog at the season of pairing, but that it was then the fashion to doubt even their existence. Yet NEEDHAM, ten years after this, while acknowledging that these bodies are found in the fluid of all animals, adopting the views of BUFFON and DAUBENTON, stated that they do not exist until after the fluid is removed from the vessels, and decomposition has commenced[‖]. And later still, even in our own time, their existence has been denied in the most positive manner by Sir EVERARD HOME[¶]. SPALLANZANI, however, was so well acquainted with them, as found in the Frog and Toad, that he has recorded his great surprise at not observing them in the latter on two occasions[**]. BONNET[††] and GLEICHEN[‡‡], also, well knew them to abound in the males of animals of distinct species at the season of impregnation, but discovered that they are usually absent in hybrids, a fact that has since been confirmed by PREVOST and DUMAS[§§]. These two observers, regarding the spermatic bodies, with LEEWENHOEK, as essential elements of the semen, believed that they actually penetrate bodily into the ovum, and become by metamorphosis part of the future embryo. Still more recently it has been stated by Dr. BARRY[‖‖] to this Society that he has actually seen the spermatozoon within the ovum, a statement which my own observations do not enable me to confirm.

Before any satisfactory conclusion could be arrived at respecting the importance of the spermatic bodies in impregnation, it was necessary to ascertain their nature, to trace their mode of development and production, to establish the periods of their occurrence in different classes of animals, and to learn something of their chemical composition, as well also as of the fluid portion of the semen in which they move. Most of these inquiries have been well followed out by WAGNER, SIEBOLD, MULLER, and more especially KÖLLIKER, and more recently by WAGNER and LEUCKARDT, from whose labours we have now some positive information which enables us to deduce a fair conclusion respecting their function, although a direct proof of its correctness is still to be supplied. Most observers now believe with KÖLLIKER that the spermatozoa (still so called) are not independent living organisms, but are merely elementary constituent parts of the male body, an opinion in which my own investigations lead me fully to coincide. This opinion, indeed, is not entirely new, as a like view was held by some observers at the beginning of the last century, when it was still questioned whether the spermatozoa are normal constituents of the semen. Dr. DRAKE*, in his "New System of Anatomy," while acknowledging that he had seen the seminal animalcules, and combating on the one hand the theory of LEEWENHOEK respecting them, and on the other the view that had previously been held with regard to the ovum, doubted their separate organization, and suggested that they "may be nothing more than some large particles of mixed fluid, whose motions and different figure the microscope discovers to our eyes," &c. G. TREVIRANUS† more recently held a similar opinion, that they are not independent animals, but are analogous in their structure and properties to particles in the pollen of plants, and that their motion is of the kind discovered by ROBERT BROWN in vegetables. KÖLLIKER‡, however, first distinctly referred them to a class of known organic constituents of the living body, the vibratile cilia, a view which had previously been discussed and inclined to by MÜLLER§.

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[*] Philosophical Transactions, 1667, vol. xii. p. 1040.

[†] Philosophical Observations on the Analogy between the Propagation of Animals and that of Vegetables. 8vo. 1752 (note), p. 44.

[‡] Physikalische Beobachtungen der Samenthierchen. Nuremb. 1756. And also, "Beyträge zu denen Beobachtungen deerer Saamenthiergen und Kleiste Aale gehörig. 12mo. Frankfurt und Leipzig, 1759."

[§] Book of Nature, folio, part 2 (note), p. 105, 1758.

[‖] Notes des Nouvelles Recherches sur les Découvertes Microscopiques de l'Abbé SPALLANZANI par M. NEEDHAM. Lond. 1769, tom. i. p. 196.

[¶] Lectures on Comparative Anatomy, 4to, vol. v. pp. 332 and 337. 1828.

[**] Dissertations relative to the Natural History of Animals and Vegetables. Lond. 1789, p. 151.

[††] "Contemplations de la Nature;" and "Œuvres d'Histoire Naturelle," 4to, tom. iii. p. 454, &c. 1779.

[‡‡] Abhandlung über der Samen- und Infusionsthierchen. Nuremb. 1788.

[§§] Annales des Sciences Naturelles (Prem. Série), tom. i. p. 182, 1824.

[‖‖] Proceedings of the Royal Society, vol. iv. p. 432. Phil. Trans. part 1, 1843, p. 33.

But however much our knowledge has become settled in regard to the nature of the spermatic bodies themselves, and their mode of development, their relation to the fluid portion of the semen in which they are contained is still a matter of doubt. H. GOODSIR|| regards certain albuminous flakes in the fluid portions of the semen of Crustacea as the debris of dissolved cells, and as the source of nourishment and development of the spermatozoa; while a more recent observer, Dr. KIRKES¶, regards the spermatozoa as the elaborators of the fluid, and the conveyers of it to the ovum at the time of impregnation. This latter supposition was originally advocated by WAGNER, VALENTINE and BISCHOFF. But two of these observers have recently changed their views**, and now regard the fluid portion as only of secondary importance in impregnation, and the spermatic bodies as of essential. This view, as WAGNER states††, is founded chiefly on the fact that in some of the invertebrata the whole mass

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* New System of Anatomy, by JAMES DRAKE, M.D., F.R.S. vol. i. p. 352, 1707.

† TIEDEMANN, Zeitschrift, vol. v. part 2, 1835.

‡ Beiträge zur Kenntniss der Geschlechtsverhältnisse und der Samen-flussigkeit wirbelloser Thiere. Berlin, 1841.

§ Elements of Physiology (Eng. ed.), part 6, 1841, p. 1478.

|| Anatomical and Pathological Researches, 1844, p. 40.

¶ Handbook of Physiology, 1848, p. 610.

** BISCHOFF in MÜLLER's Archiv, 1847. WAGNER in Article "Semen," Cyclopædia of Anatomy and Physiology, part xxxvi. January 1849.

†† *Loc. cit.* p. 507.

of the semen appears to be constituted almost or entirely of spermatozoa, while scarcely any *liquor seminis* can be detected;—and further, on the great improbability, perhaps impossibility, of the liquor seminis of those animals which expel their ova into water before impregnation being brought into contact with the ovum. But the same author justly remarks, that "even up to the present day this hypothesis of the influence of the liquor seminis has not met with any direct refutation." To this I may add, that however strong the presumption may be in favour of the agency of the spermatozoa in those instances in which a liquor seminis has not been observed, it affords no sufficient reason for disbelieving that the spermatozoa are not resolved into fluid at the moment of fecundation; or that in those animals in which the liquor seminis occurs in abundance it is not that which impregnates the ovum.

The question then, so far as *proof* is concerned, both of the direct agency of the spermatozoa, and of the non-efficiency of the liquor seminis in impregnation, remains open, as well also as that which involves the knowledge as to how impregnation is effected.

It is to these questions that this communication which I have now the honour of laying before the Royal Society is chiefly directed. I propose *first* to show the time and mode of disappearance of the germinal vesicle, and the condition of the ovum in the Frog and Newt, immediately before and after impregnation, and to endeavour to supply proof from actual experiments that the spermatozoa alone, in all cases of communion of the sexes, are the sole agents in impregnating the ovum; and further, that impregnation *cannot* be effected by the *liquor seminis*; and next to examine in what way the agency of the spermatozoa is influenced, impeded, or exerted.

1. CHANGES IN THE OVUM WITHIN THE BODY.

The ovum of the Amphibia has so frequently been the subject of examination by the best observers that a further detailed account of its development may at first appear to be useless, after what we already know of its changes through the labours of SWAMMERDAM, LEEWENHOEK, ROESEL, SPALLANZANI, PREVOST and DUMAS, RUSCONI, BAER, REICHERT, VOGT, BELL and others. But apart from the fact already mentioned, that the ovum of the Amphibia affords us the best means of actual experiment on impregnation, there are questions which relate to its earlier conditions on which the observers named are not agreed, but which are of importance with regard to the physiology of reproduction in the whole of the vertebrata.

I shall state, therefore, what I have myself observed with regard to these questions from the time when the ovarian ovum is approaching to maturity to that of its expulsion from the body, before entering on the subject of its impregnation.

As our means of comparing and testing the accuracy of all observations in natural history, and of experimental results in physiology, depend mainly on the correct identification of the objects examined, I may here state at once that the objects of the following details have been the Frog, *Rana temporaria*, and the Toad, *Bufo vul-*

garis, among the *Anoura*; and the *Triton palustris, Lissotriton punctatus* and *L. palmipes,* among the Water Newts, the *Urodela.* Neither Spallanzani, Prevost and Dumas, nor Rusconi, to whose observations I shall have frequent occasion to refer, mention the species they have examined. Spallanzani has given only the popular names of his animals, but Rusconi has given a figure of his, which appears to have been *Rana esculenta,* and as the description he has given of the ovum of this species agrees with the description given by Prevost and Dumas, it is probable that the species they employed was the same.

The Ovarium Ovum.—When the frog, *Rana temporaria,* is examined in the autumn, after it has ceased to feed, and is preparing to retire to its winter quarters, the ova within it have already attained to more than two-thirds of their ultimate dimensions before leaving the ovaries, and have begun to distend the abdomen. They remain in this state through the greater part of the winter, while the frog is hybernating, as Professor Bell remarks*, in the mud at the bottom of ponds and stagnant waters. But as the spring approaches, and the animal is aroused from its lethargy by increased temperature, the ova then rapidly acquire their full development. A female frog, taken at the end of September, with her body enlarged with ova, was confined in water in a cold room, undisturbed through the winter, excepting only at intervals of examination. The weather being mild, and the temperature of the room during October and November being sometimes at or but little below 50° Fahr., the frog remained active, and came frequently to the surface to respire. In December the temperature sunk to below 40° Fahr., when the frog became lethargic, and scarcely changed its place at the bottom of the water during nearly a fortnight, while the temperature was almost stationary, and ranged only from 35° Fahr. to 37° Fahr. On the 10th of January, when it had again risen to 40° Fahr., and that of the water to 37°·5 Fahr., the animal was still submerged and motionless; but on sudden exposure to the light of a candle it crept languidly, and almost imperceptibly, to a distance of about two inches, and again became quiet. On the 26th of January the temperature of the room had risen gradually and continuously to 52° Fahr., and that of the water to 48° Fahr., but the frog remained submerged and perfectly quiet with its eyes partially closed. Although it was not cognizant of any object by sight, the irritability of its body was now much increased, as it moved instantly when touched ever so lightly, but quickly relapsed into its previous state of rest. On the morning of the 1st of February, the temperature being then 48° Fahr., it was still submerged and motionless, but in the evening, when the warmth was increased to 52° Fahr., I found it with its nostrils only above the surface of the water, and evidently beginning to respire freely, but its eyes were completely closed. When the light of a candle was suddenly cast upon it, the eyes were slowly opened, but its body remained immoveable. On the following day, February 2, it was evident that its hybernation had been brought to a close, as it was then active, with its head out of the water, and its eyes widely open, and perfectly alive to external objects, as when the hand was slowly approached it withdrew beneath the water. The temperature at this time was 53° FAHR. During this period of hybernation the frog became slightly emaciated, and its abdomen, instead of being more enlarged, was somewhat diminished in bulk,—a good proof that during the inactivity of the respiratory and circulatory functions, the secretory also are lessened, and the development of the ova is arrested. But although no food was supplied to the frog at this time, and none probably is taken by the creature in its natural haunts, as at the time it comes forth but few of the objects on which it feeds are abroad, its body soon became enlarged, showing that the ova were then rapidly attaining their full development. Between the 2nd and 22nd of February the temperature of the room was occasionally as low as 42° FAHR., yet the creature remained active beneath the water, without relapsing into its previous state of hybernation. It only continued longer beneath the surface without rising to respire. At this period, having found that some frogs in their natural haunts had already come forth, I removed the subject of these observations also from the water to a damp locality, and on the following day found it greatly changed in appearance. While confined in the water it was of a dull dirty brown colour, but some hours after its removal it cast its tegument, and changed to a bright yellow, with the usual brown markings, and had increased in size, both in its body and limbs.

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* History of British Reptiles, 1832, p. 89.

The conclusion to which these circumstances seemed to lead was, that quickly after the frog leaves its hybernaculum, it casts its tegument as the insect escapes from its puparium, and acquires new vigour, while the ova are attaining their full growth. The Toad undergoes a similar change. About a fortnight later in the season than the Frog, I have seen many toads in a shallow ditch of slow moving water in the act of casting their dark brown tegument, and acquiring one of a greenish yellow.

On examining several frogs taken from their natural haunts, I found them in, as nearly as posible, the same state of development with regard to the ova, judging from external appearance, as the specimen I had watched through the winter. A few had just paired, but the majority were still single. On opening the bodies of the latter, I found the ovaries greatly enlarged, and the ova apparently ripe, but still contained in the ovisacs.

It is at this period, therefore, immediately after hybernation, and before the ova have left the ovaries, that the condition of the ovum is a matter of great interest with reference to the structure and contents of the germinal vesicle, the period at which the vesicle is changed or disappears, and the circumstances under which the ovum escapes from the ovary, and is received into the oviduct.

The Germinal Vesicle.—The fate of the germinal vesicle in the matured ovum is still a matter of doubt. Previous to the embryological researches of Dr. MARTIN BARRY, it was usually believed that the vesicle entirely disappears before or at the time of fecundation of the ovum. But this view was combated by the author named, who, quoting the opinions of previous inquirers, contended that the germinal vesicle in

Fig. 6

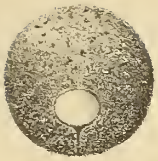


Fig. 5

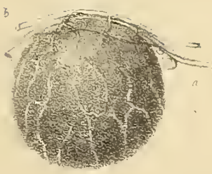


Fig. 7

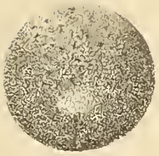


Fig. 11

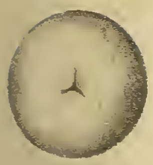


Fig. 12

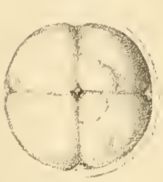


Fig. 1

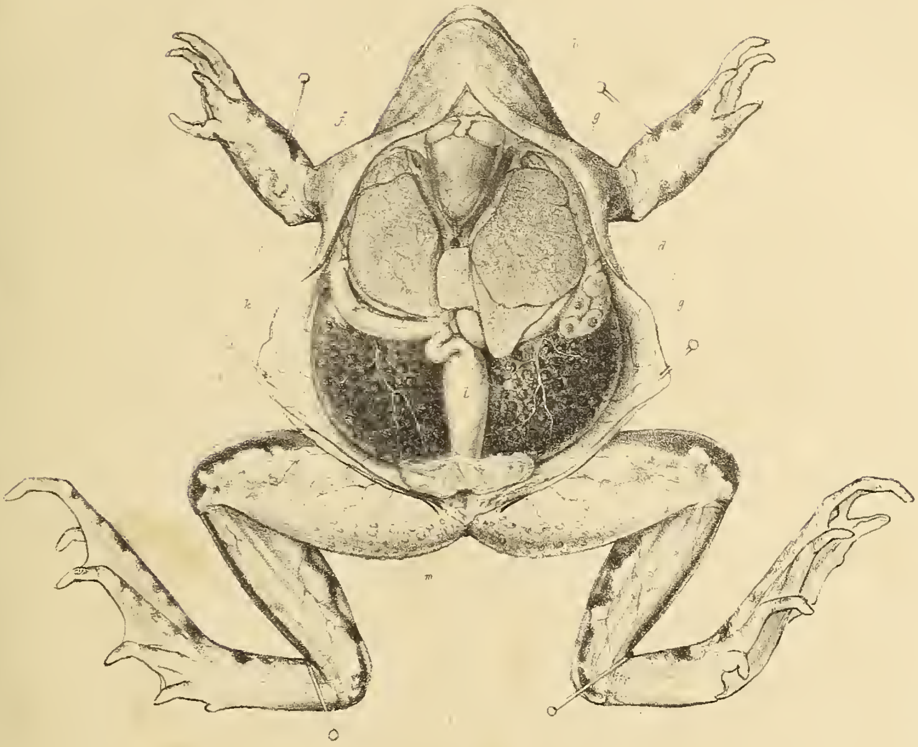


Fig. 8

Fig. 10

Fig. 9.

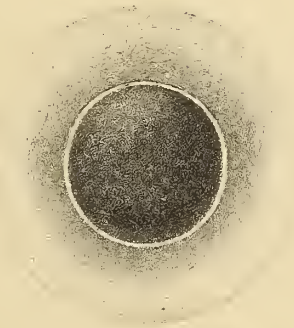


Fig. 3

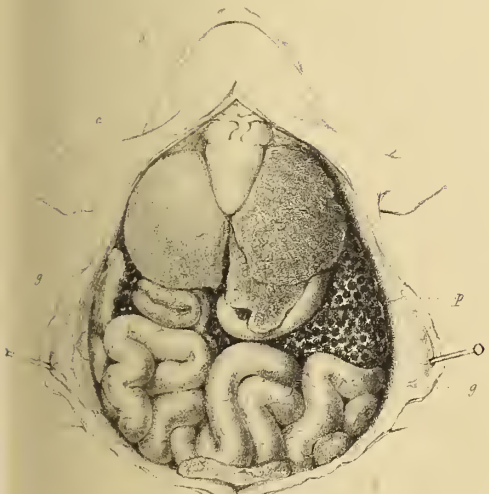
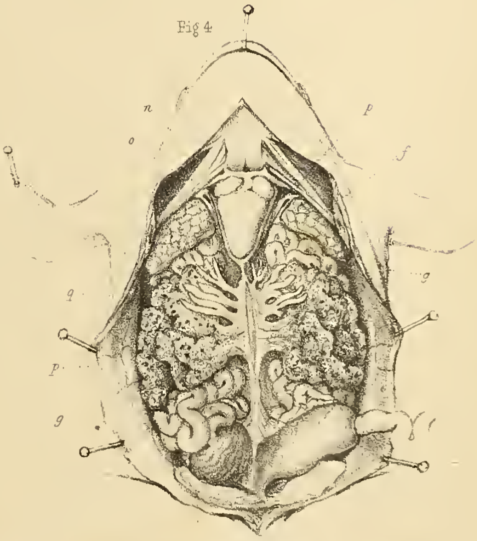


Fig. 4



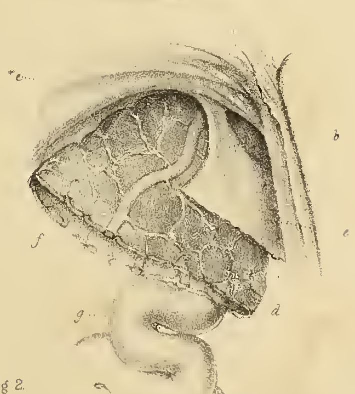


Fig. 2.

Newport, del. Ford & George, Lithographers, Hatton Garden. W Wing lith.

BRITISH MUSEUM NATURAL HISTORY.

Mammalia does not disappear, as believed by PURKINJE[*], in Birds and Amphibia, by bursting during the generative act, and pouring its contents into the germinal layer of the fecundated ovum. Neither, as supposed by BAER[†], by being urged forwards and burst between the vitellus and its membrane before fecundation. Nor, as stated by RATHKE[‡], with reference to the Crustacea, by disappearing while still within the ovary. Or, as supposed by WHARTON JONES[§], in Birds and Amphibia, by approaching the surface of the yelk, and by the giving way of the coats of the vesicle, and the effusion of its contents on the surrounding surface of the yelk. Or, further, as believed by BISCHOFF[‖], by disappearing at the time of exit of the ovum from the ovary. On the contrary, Dr. BARRY has stated that the germinal vesicle returns to the centre of the ovum, and the germinal spot to the centre of the vesicle, before the ovum leaves the ovary, and that these do not become dissolved, but only are changed in character by a process of cell development within them, which ends in the production of two cells in the centre of the yelk, which are the foundation of the body of the future embryo.

Perhaps what I am about to mention may assist us to reconcile or correct the views of this embryologist, as well as those of the authorities he has quoted. It is well known that if the ovum of the Frog is examined before the yelk has attained to one-half of its ultimate dimensions, the germinal vesicle is distinctly visible as a large circular body near the centre of the yelk, apparently granular in its interior, and more opake than the yelk itself. In the centre of the vesicle its nucleus, the germinal spot, is then equally distinct. If the ovum is examined when it has nearly acquired its full dimensions, the vesicle is still found to exist, but, as compared with the size of the entire ovum, is relatively smaller than at earlier periods, and is recognized with more difficulty, owing chiefly to the yelk cells having both increased in number around it, and also acquired a darker colour. It is equally well known that all appearance of the vesicle is lost in the Amphibia, as in Birds, before the ovum is prepared for fecundation; but as to the way in which it disappears, observers are not agreed, or even as to the time.

Structure of the Germinal Vesicle.—Having collected a number of frogs that had recently left their hybernacula, and had not yet paired, I placed some in spirit for examination. On dissecting them afterwards, I found that in some the ova had nearly reached maturity, but had not left the ovary (Plate XIV. fig. 2 *p*). The yelks being rendered firm by the spirit, I was able, by gentle pressure, to break open some of these beneath the microscope, without diffluence of the contents. The aggregated yelk cells were then seen to consist of two kinds; the one dark-coloured, which form the upper portion of the yelk, and which diminish in intensity of colour from brown or black at the circumference to a leaden or grey in the centre; the other, which forms the inferior portion, consisting of cells that become lighter-coloured as they approach the surface. The whole form a mass of nucleated cells of nearly uniform size, closely aggregated together. In the interior of the yelk, amidst the dark-coloured cells, and *much more near the surface of the dark* than that of the white portion of the ovum, I was surprised to find the germinal vesicle still entire (fig. 6), and of a somewhat oval, lenticular form, although irregularly compressed by the contraction of the whole egg in the spirit. It was of a dense white colour, and opake, from the action of the spirit, and was in striking contrast to the dark cells of the yelk, which adhered to its surface, and amidst which it lay imbedded like the kernel in a peach or apricot. On the surface of the black portion of the yelk was a minute orifice, already noticed by PREVOST and DUMAS*, the outlet of a canal that passes through this portion of the yelk to the germinal vesicle in its interior (fig. 6). This I believe to be the result of the yelk cells having only imperfectly closed around the germinal vesicle. It is however of some consequence in the future development of the ovum, as it is in this canal that the cleavage of the yelk is commenced. The vitelline membrane was already formed, but I could not discover any orifice or perforation in it, either corresponding to the canal in the yelk, or to any other part of the surface. It is not possible to mistake the germinal vesicle for any portion of the lighter substance of the yelk,—first, from the fact that the vesicle at this period is of an intense, opake, white colour, very different from that of the yelk substance,—next, from its being completely isolated from the lighter, and imbedded in the dark substance,—and lastly, from its being still invested with a distinct envelope. On removing the vesicle, and examining it separately, first, as taken from the yelk, without crushing it, and next by gentle compression, and with the highest powers of the microscope, the interior was seen to be filled with secondary cells. Each of these, formed by a distinct envelope, *appeared* to contain other, or tertiary cells, and strongly reminded me of the developmental cells of the spermatozoa in the male organs, since these again seemed to contain granules, or quaternary cells. In the midst of the secondary cells I was able to distinguish, in the centre of the germinal vesicle, in some specimens, one or two cells of larger size than the rest, and which I regarded as the remains of the germinal spot, or central nucleus. In those ova which, from their size and general appearance, seemed to be the most mature, the peripheral series of cells within the germinal vesicle were of smaller diameter than those nearer to the centre, as if the earlier developed secondary cells had disappeared and liberated their contents. The cells of the dark portion of the yelk that adhered to the germinal vesicle were also nucleated, but were of much smaller size than the peripheral cells of this body. I must remark, however, that saving the fact noticed, of having seen in some vesicles one or two cells near the centre of larger size than the rest, I have not been able to distinguish any separate nucleus, or germinal spot, which seems, at this time, to have disappeared as a distinct body. The germinal vesicle thus near its maturity is a mother-cell that contains a multitude of daughter or secondary cells, each, apparently, including its own progeny.

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[*] Symbolæ ad Ovi Avium Historiam ante Incubationem, 1825; and Article "Ei," Encyclop. Wörterbuch, Band x. p. 112, 1834.

[†] "Lettre sur la Formation de l'Œuf," in Breschet. Repertorium, 1829.

[‡] Untersuchungen ueber die Bildung und Entwickelung des Fluss Krebses, fol. Leipzig, 1829.

[§] Philosophical Transactions, 1837, part 2.

[‖] R. WAGNER's Lehrbuch, &c., 1839.

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* *Loc. cit.* tom. ii. p. 104.

It is thus certain that the germinal vesicle exists in the ovum of the Frog until after the period of hybernation. But in individuals that have been several days abroad, and in which the ova are so far matured as greatly to distend the body, and be nearly ready to leave the ovisacs, I have not always been able to detect the vesicle. The yelk has then a greater proportion of white substance in its interior, intermingled with the dark, and this, I suspect, is the result of the disappearance of the vesicle.

In the ovum of the *Toad*, when as nearly mature as that of the Frog before leaving the ovisacs, I have been unable to detect any trace of the germinal vesicle. The dark portion of the yelk is then quite distinct from the light, and forms a cortical stratum of intensely black pigment, scarcely more than one-sixth of the diameter of the yelk in thickness. The light portion is of a yellowish white, and from which the germinal vesicle, when present, is not readily distinguished. But at a little earlier period, although only a few days before the pairing of the Toad, I have found the vesicle fully as large and as distinct as before its disappearance in the egg of the Frog, but situated more distant from the centre, and nearer to the black, the future dorsal surface of the egg.

In the great Water Newt, *Triton palustris*, the yelk of the matured ovarian ovum is of a dull pea-green colour, which in spirit is changed to a greenish yellow. On breaking open the yelk of this species, after it has been hardened in spirit, I have always found the germinal vesicle of the same opake, intense white colour, of precisely the same structure, and situated in the same part of the yelk as in the Frog. It has also a canal passing from the middle of the surface of the darker-coloured portion of the yelk, through its substance to the vesicle, as in the Frog.

In the lesser Newts, *Lissotriton punctatus* and *L. palmipes*, the yelk is of a brown or liver colour on the future dorsal surface, with a white central spot, and of a white or pale straw colour on the ventral. In ripe ovarian ova of these species also I have found the germinal vesicle of the same white colour, and having the same structure as in the larger Triton and the Frog.

In each of these instances, not merely when the ovum is immature, but even when nearly ready to leave the ovisac, the germinal vesicle is situated in the interior of the yelk (fig. 6), and not immediately at the surface, and thus far the fact is in accordance with the observation of Dr. BARRY, that in the Mammalia the germinal vesicle is in the interior of the ovarian ovum, and does not disappear on the surface. But, nevertheless, it is not in the *centre* of the yelk, its place, as I have stated, is *excentric.*

Time of disappearance of the Vesicle.—It is well known that in frogs and toads the ovum is never impregnated until after it has left the body, and consequently not until long after it has left the ovary, and the germinal vesicle has entirely disappeared.

This disappearance does not, I think, take place at the instant the ovum is about to leave the ovisac, but a short time before; as I have found the ova of the Frog in one instance more matured than in that already described, still contained in the ovisacs, and yet most of them without any remains of the vesicle which I could identify as such, and with the yelks containing a larger proportion of white substance, as in the Toad. In a very few, however, the vesicle was still present, and exhibited the structure I have described. Certainly, then, the vesicle is not burst at the moment the egg escapes from the ovisac. There seems to be a short period of time between the disappearance of the vesicle and the full maturity of the ovum, during which the yelk itself undergoes some further change, and acquires the appearance noticed in the matured eggs of the Toad, and in the most advanced of those of the Frog. No trace of the germinal vesicle can be detected in any ova that have left the ovary and are contained in the cavity of the abdomen, before entering the oviducts. I have examined many ova, both of the Frog and Newt, from the abdominal cavity, but in every instance the vesicle has entirely disappeared. In some specimens, which seemed to have been in the act of escaping from the ovary when the animal was killed by immersion in spirit, I have found in the place occupied by the vesicle an aggregation of white nucleated cells, which, examined by the microscope, exhibited a close resemblance to those seen in the interior of the vesicle. In the midst of these there has occasionally been one or two of larger size than the rest, and which I have imagined to be the remains of the germinal spot, and possibly the origin of the future embryo vesicle of the impregnated ovum, an opinion, however, which I have not had the means of verifying, and I must further state that I have failed to recognize these larger cells in ova that were free in the cavity of the abdomen. Each of the three species of Newt, as well as the Frog, have presented similar appearances in the germinal vesicle and ovum under similar circumstances.

Thus it is quite certain that the germinal vesicle disappears in the Amphibia before the ovum enters the oviduct. I believe it does so in the interior of the yelk, not in the centre, but nearer to the dorsal than to the future ventral or white surface; and not, as has been supposed, on the dorsal or dark surface, between the vitellus and the vitelline membrane. This view is supported by the fact, that that portion of the yelk which incloses the vesicle in an advanced stage of the ovum in the Frog is of a more or less intense black colour, while the vesicle is perfectly white; and that at a further advanced stage, after the vesicle has disappeared, and its place is occupied by a collection of white cells, the dark portion of the yelk still preserves its intense black colour, except at the point that corresponds to the central canal, which then has a leaden hue. PREVOST and DUMAS*, and also RUSCONI†, have mentioned that there is a yellow spot at a corresponding part of the dark surface of the egg of the species they have examined after impregnation, *Rana esculenta* ?, but these appearances must not be mistaken for the germinal vesicle arrived at the surface. There is a similar spot, and that too of an elevated form, on the egg of each of the *Lissotritons*. But independent of the fact that the germinal vesicle has entirely disappeared from the interior of the egg before it escapes from the ovary, this spot is shown not to be the vesicle, both in the fact that in the egg of *Rana temporaria* the dark portion of the yelk is unchanged, while in each case the spot is perforated, and leads into the canal that passed originally to the vesicle. I regard the spot as simply a protrusion outwards of the edges of the canal while closing, after the vesicle has disappeared. I shall presently show that a similar white spot is formed on the under surface of the egg of the Frog soon after deposition, and which might equally well be mistaken for the germinal vesicle.

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* Annales des Sciences Naturelles, tom. ii. p. 104.

† Développement de la Grenouille Commune, 4to. Milan, 1826. p. 9.

Mode of disappearance of the Vesicle.—The mode in which the vesicle disappears may be inferred from the facts of its structure. Being filled with a progeny of cells which we may regard as of different periods of growth, and these again containing others, it is fair to conclude that this process of cell formation is that by which the parent vesicle is ultimately destroyed. At the time when the germinal vesicle has nearly attained its full size, the peripheral cells are smaller than those nearer to its centre, while the yelk cells that surround the vesicle are still smaller than either, and are of a dark colour. When, therefore, the vesicle has acquired its full size, by the simple vegetative endogenous growth of the contained cells, we may fairly presume that the death of the parent mother-cell, or germinal vesicle, takes place as the result of their enlargement, by the diffluence of its investing membrane; and the enclosed daughter cells, thus gradually set free in the midst of those of the yelk, as in the ideal (fig. 7), form one mass with the latter, and the moment of the actual disappearance of the vesicle thus escapes direct observation, its previous existence being indicated only by the unbroken outline of the investing membrane.

These views lead me to agree with WAGNER and BARRY in regard to the structure and mode of growth of the germinal vesicle, but not as to that by which it disappears. Dr. BARRY indeed believes that the vesicle only becomes changed by its mode of development, and does not cease to exist. But most certainly it does disappear in the Amphibia, and, as I believe, through the growth of the young cells in its interior. I cannot therefore agree with Dr. BARRY that the changes in the vesicle end in the production of two cells in the centre of the yelk, that give immediate origin to the embryo; but rather believe that it is from one of the central cells of the germinal vesicle that the future *embryo vesicle* takes its origin, while the remainder of the liberated cells are distributed with this through the substance of the yelk, when the segmentation of this body takes place. This opinion is in accordance with that of VOGT*, who found that in the ova of *Alytes obstetricans* the germinal spots increase in number, and that a few hours after fecundation small vesicles, similar to these spots, are scattered through the yelk. I have myself found similar vesicles in the fecundated egg of the Frog about three hours after impregnation (fig. 10 *a*), but have not traced them to their origin. With regard to the disappearance of the spot in the germinal vesicle, the facts observed in the ova of the Frog agree with those noticed by KÖLLIKER* in the ova of intestinal worms, that all appearance of the spot is lost before that of the vesicle. This circumstance, however, may be owing either to the spot having given origin to cells in the vesicle which quickly attain to similar dimensions, and from which it is not otherwise distinguished ; or to its becoming entirely obscured by their multiplication. Although no observations have been made on the origin of the embryo vesicle that appears in the yelk after the disappearance of the germinal, I am still inclined to regard this as being in some way derived from the lost germinal spot, notwithstanding that KÖLLIKER found a certain period of time elapse between the disappearance of the vesicle and that at which he was able to recognize this body.

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* Untersuchungen über die Entwicklungsgeschichte der Geburtshelfer-Kræte (*Alytes obstetricans*), 4to, 1842.

Transit of the Ovum.—Thus, then, when the ovum escapes from the ovisac and ovary into the cavity of the abdomen, the germinal vesicle and spot have entirely disappeared, and it consists only of the yelk enclosed in an exceedingly delicate, structureless, vitelline membrane. This is its condition in the Frog, Toad and Newts. It is then extremely delicate and easily lacerated. The mode in which the ovum passes into the oviduct has been the subject of much inquiry. I am quite certain, as SWAMMERDAM long ago showed, that the ova, when mature, pass from the ovaries into the cavity of the abdomen, and from thence into the oviducts, in the Frogs, Toads and Newts, quite independent of any intercourse with the male, as I have myself recently had an opportunity of proving. The frog I have already mentioned (p. 173.) as having watched through its season of hybernation, was kept apart from all others until the 2nd of April, at which time she had not deposited any ova. But from the altered form of her body it was evident that the ova had passed, or were at that time in the act of passing, into the oviducts. I then placed her in a vessel with others, some of which were males, but not one of these joined with her. Nevertheless, on the 6th of April she cast her ova, without having paired, and died on the following day. On examination after death, I found that the whole of the ova had left the ovaries, all of which, excepting only two still free in the cavity of the abdomen, had passed through the oviducts without any intercourse with the male. These ova of course were sterile, but it was worthy of note that their envelopes did not expand to so great an extent as those of the eggs of paired individuals.

Passage into the Oviduct.—In what way the ova pass from the cavity of the abdomen into the mouth of the duct has never been satisfactorily explained. SWAMMERDAM examined the question with much care†, but was unable to form any decided opinion respecting it, as he correctly states that the mouths of the ducts are at a distance from the ovaries, and are not free to grasp the ova like the fimbriated extremities of the Fallopian tubes in Mammalia, but are confined in the peritonæum, which is continuous with that which passes over the pericardium and heart. PREVOST and DUMAS have since stated* that the ova after leaving the ovaries are seized by the tubes ("sont saisis par des trompes"), but they do not show in what way this seizure is effected. They have omitted to describe the structure of the parts concerned in the act, and have not mentioned the way in which the ova are conveyed to the tubes from the ovaries, or whether the mouths of the tubes approach the ovaries, as in Mammalia.

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* MÜLLER's Archiv, 1843.

† Book of Nature, part 2, pp. 108, 109.

The entrance to the tubes in the Frog, as SWAMMERDAM has correctly shown, is in the peritonæum (Pl. XIV. fig. 1 *b*) at each side of the heart (*a*), and I have found it in nearly the same place in the Newts. The apex of the pericardium in the Frog is attached to the cartilage of the sternum by two layers of peritonæum, which together form the mediastinum, and enclose between them the trunk of the median abdominal vein, a branch of the vena cava. Tracing one of these layers of peritonæum upwards and over the pericardium, we find in it an orifice (fig. 1. and 2 *b*), at the part where it is reflected on itself to form the lateral portion of the suspensory ligament (*e*) of the liver (*c*). This orifice (*b*) is elongated, oval and funnel-shaped, and, when dilated, forms a kind of pouch at the anterior boundary of the space or cavity between the liver (*c*) and the heart (*a*), and laterally it is in free communication beneath the suspensory ligament with the common cavity of the abdomen. The oviduct (*g*) commences in this dilated orifice as a narrow tube with thick muscular parietes and with a thick mucous lining. It passes at first upwards and forwards, confined to the peritonæum, and then outwards above the base of the lung (*f*), gradually increasing in its dimensions. Immediately after it has passed the lung it becomes more enlarged, and as it passes backwards to the side of the spine forms many convolutions, which end in the dilated oviduct (fig. 1. and 4 *h*) or common receptacle for the eggs ready to be deposited.

The commencement of the oviduct in the Newts is very similar to that of the Frog. In the *Triton palustris* it differs only in the entrance being larger, and situated more to the side of the body, and above the lung, to the base of which, as well as to the peritonæal investment of the heart, it is confined, as in the Frog; but it has a more free communication laterally with the common cavity of the abdomen than in that animal.

The ova escape from the ovaries into the cavity of the abdomen among the viscera both in the Frogs and Newts, and are carried forwards to the spaces between the liver and heart on each side to the dilated mouth of the oviduct. They certainly are not seized by the tubes as they escape from the ovaries, as they are constantly found free in the abdominal cavity, while the mouths of the tubes being confined in the peritonæum, and having no appendages, cannot be extended to reach them. Their transfer seems to be effected in the Frog in part by the action of the abdominal muscles forcing them onwards in the spaces between the viscera, aided perhaps by the peristaltic action of the stomach and intestines; and their entrance into the tubes, when arrived in the vicinity, seems to be induced by an ingurgitory or suction action at the mouth, occasioned by the alternating and pulsatory motion of the heart, with which the tube is connected by means of the peritonæum. The tube itself is formed of strong longitudinal and transverse fibres, which are continued into the peritonæum, and the former especially into the suspensory ligament, the free external margin of which bounds the outer side of the orifice. The transverse fibres are strongly marked at the commencement of the orifice, where there is a slight pouch ; so that when the eggs are entering, these fibres doubtless prevent their return and transfer them onwards. This, I believe, is the way in which the eggs enter the oviducts. It is quite certain from the anatomy of the parts that they cannot be grasped by the oviducts until they are conveyed to them. I have not actually witnessed the passing of the eggs from the abdomen into the ducts in the Frog, but I have seen the eggs moved onwards in the smaller Newt, *Lissotriton palmipes*. Having deprived a female of this species of sensation and power of motion by division of the spinal cord through the medulla oblongata, I proceeded to open the abdomen to obtain ova from the oviducts for experiments on artificial impregnation. I then found that a number of ova were free in the abdominal cavity, and that some had very recently entered the ducts, while others were in the immediate vicinity of the mouths. The heart was still pulsating vigorously and with great regularity, and I then saw that at each pulsatory action the ova passed slowly forward between the liver and lung, towards the mouth of the oviduct, which still contained two or three ova that appeared to have entered at the moment of the operation. I did not witness the actual entrance of an ovum, but saw that the action of the heart certainly had the effect of inducing the advance of it to the mouth of the tube, and quite sufficient to lead me to regard this as one of the chief means of its entrance into the duct.

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* *Loc. cit.* tom. ii. p. 105.

It is not until the ovum has become clothed in the oviduct with its gelatinous envelope that it is susceptible of impregnation. This remark applies equally to the Frogs, Toads and Newts. The ova of the Frog and Newt at large in the abdominal cavity are always entirely without this envelope, and consist simply of the yelk mass enclosed in an extremely delicate vitelline membrane. They are so easily injured that it is only with great difficulty that they can be removed from the abdomen for examination unbroken. Those of the Newt, when taken up ever so carefully by means of a hair pencil, often burst the membrane simply by their own weight. But immediately after they have entered the oviduct and begin to acquire their envelopes, the yelk appears to undergo some change, as it becomes much firmer and is less easily injured. Shortly after the egg has entered the duct, it gains the first layer of an investment, which, from the great similarity it bears to the gelatinous layer gained by the ovum of the Rabbit in the Fallopian tube, and regarded by its discoverer in that animal, Mr. WHARTON JONES*, as the origin of the chorion, I am disposed, with him, to look upon as the analogue of that layer. This covering adheres very closely to the vitelline membrane, and is scarcely to be distinguished from it, except at certain periods of change. It is acquired before the egg has arrived at the first convolutions of the oviduct. During the remainder of its passage the egg gains two other distinct layers of similar investment, which, together, we afterwards recognize as the gelatinous envelope of the Frog and Toad, and the capsule of the Newts. These envelopes are not merely simple means of protection to the egg during the production of the embryo, as has been supposed, but, as I shall presently show, are essential to it at the period of fecundation, and without which the egg is not susceptible of impregnation. The layer of envelope which I regard as the foundation of the *chorion*, is a dense, but very transparent thin covering, in immediate contact with the vitelline membrane, and is formed of cells so closely aggregated together as to have coalesced into a fibrous structure. The two layers external to this are also formed of cells, which, with their nuclei, are distinctly visible in the envelope of *Triton palustris*, in which they alternate in regular series. Although these layers, which constitute the jelly in the egg of the Frog, become detached in that of the Newts quickly after oviposition, and, expanding as in the Frog, they leave the egg at liberty in a chamber in their interior, they are nevertheless essential to the impregnation of the ovum, which takes place before or at the time of leaving the body, as in Frogs and Toads. Rusconi* removed the envelopes of the egg of frogs, and found that the embryo still became developed, and thence concluded that these coverings serve only mechanical purposes during the changes; but it will presently be seen that they have a more important function at a much earlier period. During the time they are in course of formation around the egg the yelk undergoes some further change. The light portion becomes of a whiter, and the dark portion of a deeper colour. Internally the cells vary more in size, the lighter-coloured being the largest. I have not succeeded in recognizing any embryo or central vesicle up to this period.

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* Phil. Trans. part 2, 1837.

2. CHANGES AFTER SPAWNING AND IMPREGNATION.

First period of development.—It has been long known that a division or cleavage of the yelk of the Frog's egg is one of the earliest and apparently invariable results of fecundation. The primary division was first seen by Swammerdam, and was figured† and mentioned, but was not understood by him. Spallanzani long afterwards recognized it in the egg of the Toad (*Alytes obstetricans*‡), which he says becomes about a day after fecundation marked "with two furrows which meet to form an angle,"—that the furrows afterwards become deeper, and that "two small tumours arise on each side of the furrows,"—changes which have since been more accurately and completely described by Vogt§. Spallanzani also says that the egg of the common Toad is "marked with four furrows which intersect each other at right angles nearly like the husk of a chestnut half-opened," but he seems to have thought this was the usual condition of the ovum. To Prevost and Dumas‖, however, we owe the important discovery of the cleavage of the yelk as a process of the fecundated egg; to Rusconi[*], Baer[†] and others, its full exemplification in the Amphibia; and to Barry[‡] and Bischoff[§] its detection and elucidation in the Mammalia.

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* Développement de la Grenouille commune. Milan, 1826.

† *Loc. cit.* tab. xlviii. figs. 5, 8.

‡ *Loc. cit.* vol. ii. p. 159.

§ Untersuchungen über die Entwicklungsgeschichte der Geburtshelfer-Kræte (*Alytes obstetricans*), 1842.

‖ Annales des Sc. Nat. tom. ii. p. 110, 1824.

The agent immediately concerned in these changes is believed to be the embryo vesicle and its progeny, produced after the disappearance of the germinal vesicle. But it is yet uncertain what is the origin of the embryo vesicle, or whether it exists in the unfecundated ovum. As cleavage of the yelk certainly is not the result of the disappearance of the germinal vesicle, which disappears from all ova of the Amphibia, whether they are afterwards impregnated or not, I was desirous, at the commencement of my experiments on impregnation, to learn *from direct observation* whether the unfecundated ovum ever passes through any stage of cleavage; since the ascertainment of the fact in the negative would be an important test in the experiments I was about to make. For this purpose it was necessary to collect many pairs of frogs at the proper season, and when from symptoms which are soon recognized, it was found they were about to cast their ova, to wait patiently, perhaps for many hours, for the result, in order that the exact condition of the ovum, impregnated naturally, should be first ascertained. Swammerdam long ago remarked that the spawning of the frog takes place very rapidly "by a single effort[‖]." It is often completed, as I have found in the English species, in a few seconds, and usually in less than a minute, during which the male impregnates them, so that if the animals are not closely watched the opportunity of observing the earliest appearances of the ovum is lost. Having noted the condition of the impregnated ova of several pairs of frogs within the first few minutes after spawning, I found those of different individuals vary much with respect to the white or inferior surface, and exhibit appearances that may readily be mistaken for the breaking up of a vesicle on the surface. This appearance is due to a more or less complete state of maturity of the eggs of different broods, and according as their spawning has been retarded or hastened. The peculiarities are the most marked in the least matured, the white surface of the egg being the last completed part, and forming the base of the egg in the ovisac (fig. 5). Having noticed the appearances of the eggs when impregnated naturally, I was enabled to compare them with others impregnated artificially, and these with some of the same brood not impregnated.

Immediately after the frog has spawned the ova form a close rounded mass, which at first is scarcely so large as a walnut. They then seem to consist almost entirely of dark-coloured yelks with thin gelatinous envelopes. The form of the egg is then somewhat oval, with the white portion a little more conical than the dark and differing slightly in different ova. In some there is a dark spot in the centre of the white, that looks like a depression or cavity, or perhaps a vesicle. I am not certain that this appearance is in reality a vesicle, and therefore am content to describe it as a spot, although it conveys the idea of being a vesicle. In some ova there are two, four or six of these spots imbedded each in a small portion of white substance. When only a single spot exists, the white surface of the egg for some space around it is more defined than afterwards, and exhibits faint indications of a crucial division of the yelk on this surface immediately around the spot. This is the condition of a few ova immediately after spawning; but the majority have then advanced farther in their changes, and show four or six rounded dark-coloured spots at a little distance in the place of the single central one. When four spots occur they are usually arranged in a quadrangle, and are less than their own diameter apart. They convey the idea of being derived from the central one; but I have never seen any division of this, and if such division takes place, I think it must occur before or at the very moment the ova are expelled. In a further advanced stage of the ovum the four dark spots have become larger, and are each imbedded in a distinct portion of the white surface.

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[*] *Loc. cit.*

[†] Müller's Archiv, 1834.

[‡] Philosophical Transactions, 1839, 1840.

[§] Entwickelungsgeschichte des Kaninchen-eies, 1842.

[‖] *Loc. cit.* part 2. p 111.

One minute after deposition the spots are more widely separated, and are then each encircled by a separate patch of white substance. *Two minutes* after spawning six dark spots have made their appearance, one of which is situated nearly in the centre, and the remaining five are so arranged around this that the white patches in which they were imbedded seem to have coalesced. In *three minutes* the spots are further enlarged, and appear joined by a dark line of colour extending from each, so that the whole form, as it were, a knotted ring that includes a patch of the white surface of the yelk with one of the dark spots near the centre. In *four minutes* the ring around the included white substance is more distinct, and the white surface of the egg has increased in extent. In a further advanced stage at this period the white portion included in the ring exhibits the appearance of a white, very opake patch, the dark spot in the centre having disappeared. Around this opake white patch is the dark-coloured knotted ring, now become more uniform, and resembling a ragged chink or slight circular furrow or division in the white surface. The centre of this hemisphere of the egg thus comes to be occupied by a white patch instead of the dark spot. At *five minutes* this central white patch,—which, as before stated, and from what afterwards occurs, may readily be mistaken, on casual inspection, for the germinal vesicle, altered in its appearance and arrived at the surface,—were it not that we now know that this has long before entirely disappeared,—becomes more defined, and the dark circle around it is more uniform and distinct. At *ten minutes* the central patch is a little reduced in size, and the circle that incloses it begins to take the appearance of a diffused halo. At *fifteen minutes* the central white patch is more reduced, and the halo is spread wider, while the whole of this hemisphere of the egg has acquired a whiter appearance, and become more distinct from the dark colour of the sides and future dorsal hemisphere. At *twenty minutes* the central patch has become still smaller and rounder, and the dark halo much broader.

At this period an interesting circumstance occurs which may hereafter be found to have some reference to changes in the interior of the yelk, possibly to some rapid evolution of the so-called central or embryo vesicle in the locality originally occupied by the germinal vesicle and spot, which, as we have seen, is nearest to the dark surface —it is the partial rotation of the entire yelk. Up to about this period the ova remain undisturbed in the water in a mass as they are expelled, and lie indiscriminately, some with the dark and some with the white portion of the yelk uppermost, or horizontal. But during the time that has passed since the ova have been in contact with water, the envelopes have imbibed fluid and expanded until these investments of the yelk have acquired a thickness equal to about two-thirds of the diameter of the yelk itself. The yelks that have remained to this time with their white surface uppermost now change their position spontaneously by a partial rotation of the whole mass of each on its axis, within the vitelline membrane, until the dark surface of the whole is placed uppermost. Whether this change of position is merely the result of an expansion of the vitelline membrane at this period, when the ovum is rapidly ceasing to be susceptible of impregnation, as I shall presently show is the case after this lapse of time in the water, or whether it be also connected, as we may fairly believe, with changes going on in the interior of the yelk, I am not prepared to decide. It is important, however, to note that the change takes place at about the time at which I have found a great abundance of bright clear rounded vesicles distributed throughout the yelk, but chiefly in the place originally occupied by the germinal vesicle. In some of these vesicles, which I regard as the progeny of the germinal vesicle, I have seen irregular-shaped nuclei that appeared to be formed of a multitude of nucleoli. These vesicles convey to me the same idea as those seen by BISCHOFF in mammalian ova, excepting only that in the egg of the Frog they contain compound nuclei.

At *thirty minutes* the central patch on the white surface of the egg has almost disappeared, and the halo around it is still more diffused. At *forty-five minutes* it has entirely disappeared in most specimens, and its place is occupied by a broad dark area which includes the boundary of the previous halo, and which appears to be occasioned by a slight depression in the centre of this surface of the yelk. *One hour* after spawning this depression is somewhat deeper. The white surface has become still more defined, and the dark has acquired a more intensely black colour. The egg remains in this state without further perceptible change during the succeeding *second* and *third hour*, excepting only that the depression in the white surface becomes a little deeper, but it has almost disappeared at the end of the *fourth* hour, when *segmentation* or cleavage of the yelk is about to take place. But this is not invariably the case. When it does remain it is always of an oval form, and the primary cleavage of the yelk, as it proceeds on either side from above downwards, meets in its centre and invariably passes through it transversely to its long diameter. These are the first perceptible changes in ova that are impregnated by the natural union of the sexes, and when spawning has not been retarded. But in some broods of eggs that have been retained longer than usual in the oviducts, the whole of these changes have already taken place, in so far as regards those of the yelk, the white surface of which then exhibits an uniform appearance.

Changes immediately before segmentation or cleavage of the yelk.—Segmentation usually commences in from four to five hours. At about *one hour and a half* after spawning, the peripheral layer of cells on the middle of the dark or uppermost portion of the yelk of the impregnated ovum becomes separated from the inner surface of the vitelline membrane, and this separation goes on until a broad free space is left between this envelope and the superior layer of yelk-cells. This space, which we may designate the *respiratory chamber*, is at first but a small area above the middle of the dark surface of the yelk, and is commenced above the central canal. It seems to be occasioned by a recedence towards the interior, or a shrinking, at this period, of the yelk-cells of the dark hemisphere of the egg, commencing in the centre of this part and extending gradually, but in a less degree, to the circumference. This recedence goes on until the space left between the vitelline membrane and the yelk is equal to about one-sixth of the diameter of the whole mass, when the space appears to be occupied by a very transparent fluid, interposed between the now depressed surface of the yelk and the vitelline membrane. In the centre of the black surface is the minute orifice noticed by PREVOST and DUMAS*, and BAËR†, which leads into the central canal that communicated with the germinal vesicle in the ovarian ovum. It is in the margins of this canal that segmentation is commenced. While the space or chamber between the black portion of the yelk and the vitelline membrane is being formed, and from fifteen to thirty minutes before there is any sign of cleavage, the yelk becomes extended horizontally in a direction transverse to that in which the first cleft afterwards takes place, and assumes a transitory obtuse oval form, which it retains until the yelk begins to divide. The division, as correctly shown by BAËR‡, commences in the extension in opposite directions of at first a faint indentation in the margin of the central canal, which quickly becomes deeper, and is carried across the surface of the yelk, and gradually more and more deepening and widening as it proceeds, is carried round the sides, and meeting in the middle of the depression on the under surface, or of the remains of the white patch when this has not already disappeared, is completed by passing through the middle of the yelk; which is thus divided into two portions. This first division occupies from twenty to thirty minutes before it is finished, and it is not until then that a second fissure is commenced. I have not had any opportunity of proving whether this division is the direct result of subdivision of the central vesicle, and the attraction of the yelk-cells in equal proportions around each division of that body, as believed by KÖLLIKER§, and, as it seems fair to infer, is the case; but in addition to the observation by Prof. SHARPEY||, that the contraction of the entire yelk at the commencement of these changes, and the movements he has observed among its granules as they proceed, are in favour of this opinion—I may remark, that the extension of the yelk of the Frog's

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* *Loc. cit.* tom. ii. p. 104, 1824.

† MÜLLER's Archiv, 1834.

‡ *Loc. cit.*

§ MÜLLER's Archiv, 1843.

|| QUAIN's Anat., Fifth Edition, 1848.

egg in a direction transverse to the first cleavage, may also be advanced as conformable to the same view. It is further supported by the fact which I have seen in the egg both of the Frog and Newts, that before the second or crucial cleavage is commenced the yelk becomes contracted, so that the first cleft for a time is almost imperceptible while it is extended in the transverse direction, or line of axis of the first division, after which the second or crucial cleft is commenced. To this I may add another fact which appears to be equally significant, and which occurs in the unimpregnated eggs both of the Frog and Newts, but more especially in the latter. Although no recedence of the yelk from the vitelline membrane takes place in the unimpregnated egg of the Frog, it becomes, nevertheless, slightly oval after the first few hours, but returns to its original shape some time afterwards. But the unimpregnated egg* of the Newts is not only separated from the vitelline membrane, but also is depressed, and has a distinct pit in the centre of its upper surface, and also assumes an obtuse oval form, both which it retains, when the egg is preserved in water, until decomposition has commenced.

Changes in the impregnated and unimpregnated Ovum compared.—Having traced the egg impregnated by natural union of the sexes through its first period of development, I was able to compare the phases it exhibits with those of the artificially impregnated, and these with the appearances in unimpregnated eggs of the same brood, placed under precisely similar circumstances with reference to light, heat, air, water, and locality. The ova experimented on were all procured from the same female, and the seminal fluid from the male with which she was paired, and at the time the female was about to spawn.

Spallanzani obtained unimpregnated eggs of the Frog for his experiments by opening the body of the female and removing them from the distended oviducts. This mode is exposed to the objection, that in the removal of the ova they are liable to be brought into contact with the blood of the animal from the cut vessels, and that the ova thus obtained may not be the most mature, and fitted for experiment. It seemed desirable, therefore, to obtain them by another mode,—the total withdrawal of the influence of sensation, and power of tension in the muscles by division of the spinal cord through the medulla oblongata. The attempt was made with a female frog that had been paired for several days, and, from appearances, would have deposited her ova naturally in the course of a few hours. The spinal cord was divided as quickly as possible with a strong pair of scissors immediately behind the brain, and this organ was also destroyed, so that all consciousness was annihilated. The attempt was successful. The muscles deprived of voluntary power instantly became relaxed and allowed of the ova being passed, by gentle compression of the body, through the natural passage without contact with the blood of the animal, in greater or smaller number at pleasure, and thus afforded easy means of experiment.

I may once for all state that it was in this way that the ova were always obtained in the following investigations.

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* Or, possibly, partially impregnated.

Recourse was had to a similar expedient to procure the seminal fluid from the male. SPALLANZANI had obtained the fluid, by vivisection, from the seminal vesicles themselves. But there seemed more objection to the adoption of this mode with the male than the female, the certainty of much of the fluid being lost, independent of the severity of the operation. Indeed SPALLANZANI states, that he was never able to procure more than from two to three grains from a single individual. I therefore availed myself of a habit in the male frog, and which SPALLANZANI had previously noticed and taken similar advantage of in the Newt, to obtain the fluid in greater quantities than by the mode constantly adopted by that physiologist. When the male frog, like the Newt, is taken in the hand, or slightly compressed, at the season of pairing, a quantity of fluid is immediately passed. This consists chiefly of seminal fluid mixed with water expelled from the effect of the compression, or during the efforts to escape, as water is passed by other animals at the moment of capture. It abounds with spermatozoa in their most active state, and thus is fitted for experiment. It required therefore only to secure the limbs of the animal and compress it slightly, to obtain the fluid without severe injury. This ready mode was adopted on all occasions when the fluid was required, and the precaution taken always to examine a portion with the microscope, to be assured of its nature before employing it. Spermatozoa have never, during the season of pairing, been absent from it. At the end of the season they have been less abundant, and spermatozoal cells in greater proportion than at an earlier period. But in these cases I had reason to think that the chief part of the fluid consisted of water. It is probable that this was the case in the two instances of apparent absence of spermatozoa in the Toad, mentioned by SPALLANZANI*, and that the fluid did really contain spermatozoa, although few in number, and consequently easily overlooked, and that the ova were impregnated by these, and not by the fluid portion of the semen, as he appears to have supposed.

On comparing the white surface of the yelk of the unimpregnated with that of the impregnated egg, whether the egg had been fecundated naturally or artificially, I was not able to detect any difference during the first twelve minutes. The changes went on in both, and appeared to be almost identical in each. But after the time specified no further progress was perceptible in the unimpregnated ovum, which continued to exhibit the same appearance for several hours. But the white surface of the impregnated egg became more and more changed, up to the time of cleavage of the yelk, when it was almost an uniform surface.

These observations were afterwards repeated with similar results, and the conclusion to which they led was, that changes take place in the yelk from the period when the germinal vesicle disappears and the ovum leaves the ovary to the moment of its expulsion from the body, and which changes may proceed for some time afterwards quite independent of impregnation ; and that these have some reference to the evolution of the central or embryo vesicle: possibly also that they do not cease immediately, but subside gradually when the stimulus imparted by impregnation is not supplied.

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* Dissertations relative to the Natural History of Animals and Vegetables, 1789, vol. ii. p. 151.

The experiments made to ascertain whether the unimpregnated ovum passes through any stage of cleavage, consisted of four sets, placed in four vessels of equal size, containing each about two ounces of water. Ova were passed from the same female as quickly as possible at the same time into each of these vessels. To one of these marked A, a considerable quantity of a mixture of seminal fluid, one part to three parts of water, was immediately added; to a second, B, only a single drop of this mixture; while the third and fourth, C and D, contained only water with the unimpregnated ova, and the four vessels were then placed in every other respect under precisely similar conditions.

A few minutes after the impregnating fluid had been added to A, I examined some of the ova beneath the microscope, and found a vast abundance of spermatozoa adhering to every part of the surface of their gelatinous envelopes. On other ova from the set B, there were also many spermatozoa attached, but in much smaller number than on the ova of set A.

In *five hours and fifteen minutes*, the temperature of the room during the interval having ranged only from 53° Fahr. to 54° Fahr., segmentation had commenced vigorously, and was strongly marked in the whole of set A. But it had not commenced in set B. It did not occur in these until *five hours and twenty-two minutes*, when it began in these also. Thus there were *seven minutes*' difference in the commencement of the changes in these two sets of ova, a circumstance which led to the belief that this difference might have some reference to the relative quantities of the impregnating fluid employed,—an opinion which I had long before been led to by observations on the impregnation of the common Earwig, *Forficula*, in which it had appeared to me that deficiency in the quantity of the impregnating fluid is unfavourable to fecundation.

No segmentation or cleavage of the yelk took place in the sets of ova marked C and D, which, except in becoming a little oval, as already mentioned of unimpregnated eggs, remained, in so far as the appearance of the yelk surface was concerned, in the same state as at a few minutes after spawning, and they continued in exactly the same condition at the end of twenty-two hours. This I have since found constantly to be the case with unimpregnated ova, whether they happen to be exposed to a high or low temperature of the surrounding medium. The yelk of the impregnated egg gradually acquires a more intense black colour, which strikingly contrasts with the dull colour of the unimpregnated.

At the end of *six days* the majority of the ova in A and B were producing embryos, while those in C and D were fast decomposing.

These trials afforded the positive test I required from direct observation, as a fixed point in the experiments about to be commenced,—that segmentation certainly does not take place in the unimpregnated ovum.

3. SUSCEPTIBILITY OF THE OVUM.

I was not aware, at the time of commencing my experiments in March 1849, nor indeed until very recently, of the extent to which the original investigations of Spallanzani, and of Prevost and Dumas had long ago been carried*, and it has only been since my experiments were completed, and during the preparation of this paper for presentation to the Royal Society, I have learned by careful reference to their first memoirs, that they have anticipated me in part of this inquiry—that of endeavouring to separate the spermatozoa by filtration from the more fluid portion of semen, and testing the effect of these two constituents in artificial impregnation. To them therefore be all honour for the result; although even they, as they honourably mention, had themselves been anticipated in this by Spallanzani, and that too with similar success. The extraordinary results obtained by Spallanzani† in artificial impregnation, and the imperfect knowledge which we possess of the nature of the means by which it is effected, has induced me to endeavour to repeat and vary his experiment, and to conceive others, which, so far as I am aware, have not yet been attempted. I have been the more urged to this from the circumstance mentioned by Spallanzani, and already alluded to (p. 189), the occasional supposed absence of spermatozoa from fluid that is capable of fecundating; and also from a belief formed long ago with regard to the Articulata, that the spermatozoa, nevertheless, certainly are the efficient agents in impregnation, although full proof of the fact has been wanted. I have been desirous therefore of learning how far this belief can bear the test of direct experiment, or the fact be capable of demonstration by artificial means in the Amphibia. As, however, the experiments I have myself made vary from those of the authors mentioned,—have not been influenced by the result they had previously arrived at,—have been somewhat more extended, and, as I believe, will now tend to place the fact of the direct agency of the spermatozoa in impregnating the ovum beyond doubt,—it has seemed desirable still to give them in detail, as assisting to establish an important point of knowledge by facilitating a comparison of the results of independent investigations.

Duration of susceptibility.—The length of time during which the ovum, after it has been passed, remains susceptible of fecundation, is affected by several circumstances. I had reason to believe at the commencement of my experiment that this time is very short. Spallanzani found that when the egg of the Toad was expelled into water it was not susceptible of fecundation after a lapse of fifteen minutes‡. This was at a raised temperature of the atmosphere, 81°·5 Fahr. On the other hand, he also found that, at this temperature, ova retained fourteen hours within the body of the female after death, and of course not in contact with air or water, might still be fecundated; and that when preserved in an ice-house fecundation might be effected at two days after the death of the parent§. But Prevost and Dumas arrived at the conclusion||

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* Annales des Sciences Naturelles, tom. i. et ii. 1824.

† Dissertations, &c. vol. ii.

‡ *Loc. cit.* vol. ii. p. 178.

§ *Loc. cit.* vol. ii. pp. 176 and 177.

|| An. des Sc. Nat. vol. ii. p. 135.

that the time is much more extended in the Frog;—that fecundation may take place when the temperature ranges from 53° Fahr. to 59° Fahr. at the expiration of one hour after immersion of the eggs;—that some eggs are fecundated at two, and a very few even at the end of three hours, after which no fecundation takes place. The results obtained by myself both on the Frog and Toad have been most in accordance with those by Spallanzani. This is the more worthy of notice from the circumstance that a slight difference between his and mine is readily accounted for by a corresponding slight difference of temperature, which Spallanzani, and Prevost and Dumas, have remarked, and since them also Mr. Bell*, has great influence on the changes of the eggs and young. The temperature at which my test experiments were made, was a little lower even than that at which Prevost and Dumas made theirs; and yet I was not able to find any ova susceptible of fecundation after they had remained from thirty to forty minutes in water. On careful examination of Prevost and Dumas' experiments, I think the difference may perhaps be due to a circumstance which seems equally to affect some of Spallanzani's results, namely, the mode in which the impregnating fluid employed was obtained. These authors state that the fluid they employed was expressed from the testicles of the frogs, so that from what we now know of the mode of origin of the spermatozoa, this fluid in all probability contained a large proportion of developmental cells that included spermatozoa not fully matured, but which might become liberated in the water at a longer or shorter period. Or, possibly, the fluid added to ova that had been long in the water, had been very recently obtained; in which case the vigorous spermatozoa might effect the impregnation of ova that had become almost insusceptible through the imbibition of water by their envelopes. I am led to this view by the fact that the jelly-like envelope of the Frog's egg begins to imbibe and expand the instant it is brought into contact with fluid; and from having ascertained that there is a close relation between the degree of expansion and imbibition of this envelope and the susceptibility of the ovum to become impregnated, and that these conditions are also greatly affected by temperature. The act of expansion of the envelope is an act of endosmose, and possibly this is one of the means by which the impregnating agent is made to exert its influence on the yelk. The yelk is not a passive recipient during the endosmic action of its coverings, but seems to participate in that action, as I have seen portions of its surface heave and contract within the vitelline membrane during the first hour the egg has remained in water. It may thence be inferred, that if the impregnating stimulus be not supplied quickly, the fitness of the ovum to become impregnated is diminished in proportion as its envelopes are expanded. If then it be proved that the spermatozoon is the agent in impregnation, but, so far as can be discovered, does not penetrate bodily into the ovum or its envelopes, and yet, as may be shown, must always come into contact with their surface, the more rapidly and to the greater extent this expansion takes place, and removes the efficient body from that which it is in some way destined to affect, the less will be the chance of its impregnating the ovum, and the less will the ovum become susceptible of impregnation even by the most healthy and vibratile spermatozoa.

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* British Reptiles, p. 92.

The extent and rate of expansion of the envelope of the Frog's egg, during the first half-hour it remains in water, very nearly coincide with the diminution of the fitness of the ovum to become fecundated. This is shown by observing the rate of expansion of the envelope during the first fifteen minutes of submersion, and then testing the fitness of the ovum, by experiment, during a similar period.

At the *moment* when the ovum is expelled from the body, the envelope is merely a thin gelatinous layer, its entire diameter being equal only to about one-sixth of the diameter of the yelk. After it has been *one minute* in water, and begun to imbibe and expand, it is then equal to about one-fourth of the diameter of the yelk. At the end of *two minutes* it is enlarged to one-third, and in *three minutes* to one-half the diameter of this body. In *four minutes* it exceeds three-fifths, and in *six minutes* two-thirds, and it continues to imbibe fluid and expand at the same rate, until, at from *ten* to *fifteen* minutes, it very nearly equals in thickness the whole diameter of the yelk; and at *half an hour* (fig. 9) it is one-fourth greater than this. PREVOST and DUMAS* noticed the expansion of the envelope during the first *six hours*, but entirely overlooked the rate of expansion during the most important period, the first hour, and noticed only the general fact that the diameter of the envelope, at the end of the first hour and a half, was as 5 to 2·5 at the time of spawning, and that it had nearly acquired its full size at the end of three hours. My own observations agree with this latter statement. The expansion of the envelope is greatly retarded at the end of the third or fourth hour, until after cleavage of the yelk has taken place, when it again proceeds, but much more slowly than at first. If then we bear in mind the rate of expansion of the envelope during the first half-hour, the following experiments will give some idea of the degree of susceptibility of the ovum to become impregnated during that period.

Set E. April 6, 1850.—The temperature of the room, at the commencement of this set of experiments, being 60° FAHR., ova were obtained from a female frog and seminal fluid from a male, by the mode already mentioned; the latter being mixed with an equal quantity of water.

I may here remark, that the ova in each of this set of experiments were placed in nearly similar quantities of water, and that as it had been shown in the experiments A, B, C and D (p. 190), that segmentation of the yelk proves the ovum to have been impregnated, although, as we shall hereafter find, not always sufficiently so as to produce the embryo, I adopted this as a fair test of the susceptibility of the ovum. I may here also mention, that although the date of making the several experiments detailed in this paper is recorded, it has been necessary, for reasons that will be obvious, to disregard the order of time at which the several sets were made, and to detail them when considering the subject to which they more especially refer.

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* *Loc. cit.*, vol. ii. p. 108.

No. 1. P.M. $2^h 52^m$.—*Eighty-three ova* were passed into water, and the impregnating fluid added to them at the expiration of *one minute.* This was *forty-three minutes* after the fluid had been obtained and mixed with water; but on examination with the microscope at this period, the spermatozoa contained in it were still very active. This long period was determined on with a view to the more effectually testing the susceptibility of the ovum, as it will be shown that the spermatozoa are less and less efficient in proportion to the length of time they have been mixed with water. Segmentation commenced in a very large proportion of the ova at the end of *three hours and fifty-five* minutes. On the 14th of April, the *eighth day, thirty-two* embryos had been formed.

No. 2. P.M. $2^h 51^m$.—*Ninety-two ova* were passed into water, and at the expiration of *two minutes* impregnating fluid was added to the same, *forty-three minutes* after it had been obtained. Segmentation commenced in these also at *three hours and fifty-five minutes,* and took place in almost every ovum. On the *eighth day* there were *forty-five* embryos.

No. 3. P.M. $2^h 24^m$.—*One hundred and twenty-seven ova* were immersed in water for *three minutes,* and then exposed and bathed with impregnating fluid during *twenty seconds,* water being immediately afterwards added to them. No segmentation had taken place at the end of *four hours and three minutes,* but it took place in many of the ova at a later period, the exact time having escaped my notice. The fluid employed had been mixed with water only *seventeen minutes.* On the *eighth day* there were *thirty-three* embryos.

No. 4. P.M. $2^h 15^m$.—*Eighty-one ova* were exposed to the air on a dry surface for *three minutes* without having been in contact with water, and were then bathed with impregnating fluid during *five seconds* and water immediately afterwards added to them. The fluid in this experiment had been obtained only *eight minutes.* Segmentation commenced in several ova at *four hours and five minutes,* and on the eighth day there were *fifty-three* embryos.

No. 5. P.M. $2^h 25^m$.—*One hundred and thirty-six ova* were passed into water for *five minutes,* and were then exposed and bathed with impregnating fluid for *several seconds,* and water immediately afterwards added to them. The fluid had been obtained *twenty minutes.* Segmentation occurred in one ovum at *four hours and eight minutes,* and in others quickly after. On the eighth day only *ten embryos* had been formed.

No. 6. P.M. $2^h 17^m$.—*One hundred and thirty-nine ova* were exposed to the air, on a dry surface, for *five minutes,* and were then touched freely with fluid during *five seconds,* applied with a hair-pencil, and water was then quickly added to them. The fluid employed had been obtained *twelve minutes.* Segmentation took place in *four hours and eleven minutes.* On the eighth day there were *thirty-seven* embryos.

No. 7. P.M. $2^h 21^m$.—*Two hundred and five ova* were retained in water for *fifteen* *minutes,* were then exposed, well-bathed with impregnating fluid, and water immediately added to them. The fluid employed had been obtained *twenty-six minutes.* Segmentation commenced in *four hours and fourteen minutes,* but was more general in *four hours and seventeen minutes.* On the eighth day there were *forty-five* embryos.

No. 8. P.M. 2^h 24^m.—*About one hundred ova* were submerged for *half an hour,* and impregnating fluid obtained *forty-four minutes* before was then supplied to them, but not more than *six or eight ova* became segmented, and only two embryos were formed.

The following summary will more immediately indicate the results:—

Table I.—Set E.

Experiment.	Ova.	Time.	Medium.	Fluid obtained.	Segmentation.	Embryos.	Per-centage.
		″		″	′ ″		
No. 1	83	1	Water.	43	3 55	32	·38
No. 2	92	2	Water.	43	3 55	45	·49
No. 3	127	3	Water.	17	4 3	33	·26
No. 4	81	3	Air.	8	4 5	53	·65·5
No. 5	136	5	Water.	20	4 8	10	·07
No. 6	139	5	Air.	12	4 11	37	·26
No. 7	205	15	Water.	26	4 14	45	·22
No. 8	100	30	Water.	44	......	2	·02

Thus then at a temperature of 60° Fahr. the susceptibility of the ovum to become impregnated is greatest at the time it is passed into water, and for two or three minutes afterwards, and segmentation then takes place more quickly, even when the seminal fluid has been for nearly three quarters of an hour mixed with water, than after longer immersion. The fitness of the ovum to become impregnated is gradually diminished, and segmentation takes place more tardily, according to the length of time which the ovum has remained in water, as is seen by comparing the results of Nos. 1 and 2 with 7 and 8. On the other hand, while the desiccating effect of exposure to air more arrests the fecundation of the ovum and the occurrence of segmentation of the yelk than a continuance for a corresponding length of time in water, it seems to be less prejudicial to the fecundity of the ovum than immersion in that fluid, as appears to be shown by comparison of Nos. 4 and 6 with 3 and 5, the difference in the number of ova produced being too great to lead us to attribute this to difference in the length of time the impregnating fluid had been obtained.

In the foregoing set of experiments, the quantity of impregnating fluid supplied to the ova was but little attended to, it being added very freely in each case. In the following set I was desirous of knowing what difference would result from the fluid being applied more sparingly, or but for a very short space of time. Spallanzani had made experiments with a similar view, but his appeared to be open to some objections, as he had not noted some important circumstances which greatly affect the result, as the temperature of the medium, the length of time the fluid employed had been obtained, &c. In the experiments now made, these circumstances were attended to, and I noticed a curious fact which I first remarked in experiments in 1849. It is what I may designate *partial impregnation*, and is indicated by a portion only of the yelk becoming segmented. This frequently happens with ova that have been brought into contact with only very small quantities of seminal fluid, and but for short spaces of time, as in some of the following experiments. These ova, so far as I have observed, never produce embryos. Segmentation is arrested in some at the very commencement (Plate XIV. fig. 11), in others it goes on to the second or crucial fissure, and in a very few cases may proceed somewhat further (fig. 12), but is never completed to granulation of the yelk. This, I think, is a fact which deserves some consideration with reference to the formation of the embryo.

Set F. March 22, 1850.—Temperature of the room at the time of the experiment was 48°·5 Fahr., and that of the water employed 46°·5 Fahr. As the proof of impregnation is the segmentation of the yelk, and as my object now was to observe the effect of small quantities of impregnating fluid applied only for very short periods of time at a low temperature of the surrounding medium, it is not of consequence that this set was not watched to the full development of the embryo. To show the degree of susceptibility of the ovum under the combined influence of these circumstances, it was sufficient to attempt the impregnation at a low temperature, and after the lapse of an interval to remove the ova to a room of the same, or nearly the same temperature as in the set E. This was done at the end of one *hour and a half.*

No. 1. A.M. 12^h 12^m.—*Fifty-one ova,* passed on a dry surface, were each touched lightly and quickly, *once* only, with a small hair-pencil dipped in impregnating fluid mixed with water, at *eleven minutes* after it was obtained, and water was then added to them. At the expiration of one hour and a half they were removed to a room of the temperature of 59° Fahr. Segmentation did not occur until the expiration of *six hours* and *a half*, and at the end of eight days only *four* embryos had appeared.

No. 2. A.M. 12^h 20^m.—*Forty-two ova* were immersed in water for *five minutes,* and then exposed, and touched for an instant only as above, and again placed in water. The impregnating fluid had now been obtained *nineteen minutes.* Segmentation commenced in some of these at *six hours and three quarters,* but nearly all of them were only *partially impregnated,* and not a single specimen produced an embryo.

No. 3. A.M. 12^h 19^m.—*Fifty-eight ova* immersed in water for *five* minutes, were exposed, touched for an instant as above, and again immersed for *one minute,* after which, they were well rubbed in the water with a clean pencil, and fresh water then supplied to them. The fluid employed had been obtained *twenty-three* minutes.

Not a single egg gave any signs of having been impregnated, either perfectly or partially, nor did a single ovum produce an embryo.

No. 4. A.M. 12^h 23^m.—*Forty-two ova* were passed into a solution of *carmine* (the pigment employed by water-colour painters) for *five minutes,* and were then washed with water, touched for an instant, as above, with impregnating fluid at *twenty-seven minutes* after it was obtained, and water then supplied to them. Not a single egg became fully impregnated or afterwards produced an embryo. In two or three ova there were slight indications of partial impregnation.

No. 5. P.M. 12^h 37^m.—*Sixty-five ova* having remained *fifteen minutes in water*, were exposed, and thoroughly bathed with impregnating fluid applied with a hair-pencil, *fifty-one* minutes after it had been obtained, and water was then added to them. Segmentation did not take place in these ova.

No. 6. P.M. 12^h 38^m.—*Seventy-seven ova*, passed into a *solution of carmine* for *fifteen minutes*, were exposed, and thoroughly bathed with impregnating fluid as in No. 5, and water was then added; but not a single egg gave any sign of impregnation.

Influence of Temperature.—From these experiments, it seemed evident that the susceptibility of the ovum to become impregnated is diminished in proportion to the degree of expansion of its envelope and its imbibition of fluid, conditions which are greatly affected by the temperature of the medium in which the ovum is placed during the first hour; and there seems reason to suppose that this diminution may be due to the extent to which the envelope becomes influenced by temperature, rather than to any insusceptibility at that time in the yelk itself. The following experiments, made a few hours after the above, tend to support this view.

Set G. March 22, 1850. Atmosphere 48° FAHR. Water 47°.

No. 1. P.M. 4^h 30^m.—*Fifty-eight ova* were passed from the female from which the ova used in the preceding experiments were obtained, four hours and a half after division of the spinal cord; and seminal fluid mixed with water, and obtained *fifteen minutes* before, was *immediately* added to the water in which they were immersed. The ova were removed at the end of twenty-five minutes to a room in which the temperature was then 62° FAHR. Segmentation took place in almost every ovum a few minutes *within* the *sixth hour*, at which time the temperature of the air was 64° FAHR., and that of the water 62°. At the *eighth* day, *fifty-three* out of fifty-eight ova had produced embryos.

No. 2. P.M. 5^h.—*Sixty-three ova* from the same female were well bathed with impregnating fluid, and water was then added to them. The fluid in this case had been obtained three quarters of an hour. Segmentation took place in the majority of these at the end of *five hours and a half*.

No. 3. March 23. P.M. 12^h 45^m.—*One hundred and twenty-four ova* from the same female, twenty-four hours after section of the spinal cord, were passed into water, and impregnating fluid soon after it was obtained supplied to them. The ova were placed in a temperature of about 60°, and nearly the whole produced embryos.

These facts proved that the ova employed were still fitted to become impregnated when the fluid was supplied to them in sufficient abundance, and for a sufficient length of time, and within the period during which the envelope continues to expand and imbibe most rapidly. This condition is always promoted by an early removal from a low to a comparatively high temperature during the period of expansion, as in *Set* G, in which segmentation took place in from *five hours and a half to six hours*, and when the removal from low to high temperature was within the first half hour; while it did not occur, in the only experiment in which it happened in *Set* F, No. 1, until the end of *six hours and a-half*, when the removal from a similar low to a like high temperature was not made until one hour and a half after impregnation.

The influence of temperature is thus as marked in its effects on the impregnation of the ovum as it can be proved to be on the future development of the embryo. Impregnation is accelerated, and also is more certain in its occurrence in a high than in a low temperature. In the latter it becomes retarded and is less determined. This applies equally to the susceptibility of the ovum, and to the fitness of the impregnating fluid to effect impregnation. But in proportion as this fitness is exalted by increase of temperature, so is the duration of the capability to receive in the one, and the efficiency to communicate in the other diminished. SPALLANZANI found that the ova of toads placed in an ice-house could be impregnated at the end of forty-one hours[*]. PREVOST and DUMAS[†] also mention that they were successful, and that too to a great extent, with ova that had been twenty-four hours *in water*, the temperature during the period ranging from 18° Cent. (64°·4 FAHR.) to 22° Cent. (71°·6 FAHR.), and with some eggs that had not been immersed even at thirty-six hours[‡], the temperature being then from 12° Cent. to 15° Cent. (53°·6 to 59° FAHR.). The results obtained by myself have been much less successful. Out of one hundred and forty ova obtained from a female frog, killed twenty-four hours before and preserved at or below the temperature of 55°·5 FAHR., at which the experiment was made, only a very few became partially segmented, but not one produced an embryo; although an abundance of impregnating fluid, abounding with spermatozoa, and obtained only a few minutes before it was employed, had been supplied to them. It is evident therefore that this failure was due chiefly to the ova, and not to inefficiency of the impregnating fluid. On the other hand, I have been equally unsuccessful with ova from a frog that had been killed only two hours and a half when the impregnating fluid employed had been more than four hours and a half mixed with water. In this case the failure appeared to have been due chiefly to the spermatozoa, nearly the whole of which, on inspection by the microscope, were found to be motionless and appeared to have lost their vitality. At the same time it must be mentioned that the female from which the ova employed in No. 3 of the last set of experiments were obtained still existed, in so far as the vitality of the muscular system was concerned, and therefore can hardly be mentioned in comparison with MM. PREVOST and DUMAS' observation. But while the numerical results obtained by myself have been less favourable than those of SPALLANZANI or the physiologists now mentioned, the general facts, so far as they are open to comparison, are in full accordance with them. The difference in the details of our respective observations appears to have been due in chief part to the influence of temperature at the time of the impregnation of the ova, or within the first two or three hours after the impregnating fluid has been supplied. Thus, if the temperature has been gradually rising at the time of impregnation, the fecundation of the ovum, as I have stated, has more certainly taken place than when the temperature was subsiding, the condition of the ova and of the impregnating fluid employed being equally fit in each case. Spallanzani has shown that in his experiments ova did not become impregnated after they had remained fifteen minutes in water. In the experiments by myself I could rarely obtain fecundation after thirty minutes' immersion. The difference of time between these results may fairly be attributed to difference in the temperature at which the experiments were made, and in great measure to the influence of this on the endosmosis and expansion of the envelopes. But it was possible that some other agent might be concerned in these results, and that light, as well as heat and immersion in water, might greatly influence them. To put this to the test, and to learn whether the difference depends entirely or chiefly on the amount of temperature, I have made two sets of experiments at precisely the same time, performed in the same way, with ova from the same female and impregnating fluid from the same male, the only difference being that within a very few minutes after the impregnating fluid was supplied, one set was removed to a higher and slightly rising temperature, from which all light was excluded; while the other was allowed to remain freely exposed to light, but in a room of ten or twelve degrees lower temperature, and which was becoming still further reduced.

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[*] Dissertations, &c., vol. ii. p. 177.

[†] *Loc. cit.*, vol. ii. p. 140.

[‡] *Id.*, p. 134.

The influence of light and heat on the development of the embryo has already been referred to by Spallanzani, Prevost and Dumas, Rusconi, Dr. W. Edwards, and Mr. Bell. Rusconi expressly states that light has no influence on the development of the germ*, but his observations, as well as those before made by Spallanzani, show that heat has a very marked influence, and this has been fully confirmed by Dr. W. Edwards, and Professor Bell. Very recently also the subject has been referred to by Mr. Higginbottom†, and I have great pleasure in stating that my own observations on the influence of heat, and the little effect of light on the development of the tadpole, are in accordance with the observations made by him. But the object I have had most in view has been, as above stated, to mark the effect of heat, without light, on the changes of the ovum, more especially during the period of fecundation, the first three or four hours after the egg is laid; and onwards to the termination of what I shall hereafter propose to consider, when describing the development of the embryo,—as the end of the *third period*—the closure of the *laminæ dorsales* and the establishment of ciliary aëration on the surface of the body.

Set H, March 20, 1850. Atmosphere 59° Fahr. Water 57° Fahr.

No. 1. p.m. 1^{h} 14^{m}.—*Eighteen ova*, as they passed from the body of a frog, were touched lightly *once* with a hair-pencil that had been dipped in impregnating fluid obtained two minutes before, and mixed with about three parts of water. After these ova had remained ten minutes in water, this was removed and fresh supplied.

These ova assumed the ovoid form at the expiration of three hours and thirty-six

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* *Loc. cit.*, p. 20.

† Proceedings of the Royal Society, May 16, 1850; and Phil. Trans. Part II., 1850.

minutes, and segmentation commenced at *three hours and fifty-six minutes*, and was general in two minutes longer, at which time the temperature of the dark cupboard in which the ova of this set of experiments were placed had been raised to 64° FAHR., and that of the water they were contained in to 60° FAHR.

In four days and a half, thirteen of these ova had produced embryos that were then at the end of the *third period* of development, and on the eighth day the whole of them had advanced to the period when they leave the ovum and attach themselves to the exterior of the envelopes,—the end of the *fourth period* of development. The mean temperature of the locality in which these ova and the embryos produced from them were placed, was about 60° FAHR. for the entire period of eight days.

No. 2. P.M. 1^h 55^m.—*Forty-eight ova* were touched *once*, as they passed from the body of the frog, with a hair-pencil that had been dipped in a small quantity of residual fluid retained with spermatozoa on a filter, in separating these from the fluid portion of frog's semen, obtained and mixed with water forty minutes previous.

The temperature of the cupboard having been raised as in No. 1, segmentation commenced in *three hours* and *fifty-five minutes*, but was more general in *four hours*. Many of these ova were only partially impregnated, and of consequence did not produce embryos. Others passed through their changes, as in No. 1, and in nearly similar periods of time. On the eighth day *ten embryos* had been produced.

No. 3. P.M. 2^h 3^m.—*Fifty-seven ova* were well bathed as they passed from the frog with the fluid portion of semen that had passed through two filter papers and been separated from most of the spermatozoa, and which when examined with the microscope was found to contain only a very few of these bodies.

No segmentation had taken place in any of these ova at the end of *four hours and five minutes*, but several had become ovoid. At *four hours and thirty-seven minutes* segmentation had taken place in *one ovum*, and this alone produced an embryo.

Set I, March 20, 1850. Atmosphere 48° FAHR. Water 47° FAHR.—This set was the counterpart of the preceding, *Set* H.

No. 1. P.M. 1^h 15^m.—*Nineteen ova* were treated in exactly the same way as in No. 1 H, and at the expiration of ten minutes were removed to fresh water, and placed where they were most exposed to light.

No segmentation occurred in any of these ova until the expiration of *seven hours and forty-five minutes*. The temperature of the room had then sunk to 47° FAHR., and that of the water with the ova to 46° FAHR. All the changes in these ova were so exceedingly slow, that at the end of the eighteenth hour, the temperature during the interval becoming slightly further reduced, the segmentation of the yelk had not advanced further than to the formation of the first equatorial and secondary median furrows. On the fifth day the development of the germ had not proceeded further than to the commencement of the formation of the *area germinativa*, the end of the *second period*, the mean temperature during the interval having been 45°·49 FAHR.; while the ova in No. 1 H had reached the end of the third period, the mean temperature in which they had been retained being 59°·5 Fahr. On the *eighth day*, when, as already shown, the *thirteen embryos* of No. 1 H had left the egg, only *three* had been developed in this set of observations, No. 1 I, and these had reached only to the commencement of the formation of the laminæ dorsales, the mean temperature of the room during the entire period being then advanced to 45°·72 Fahr.; and the completion of their third phase of development did not take place until the *tenth or eleventh day*.

Thus while *three embryos* only were produced in this experiment, No. 1 I, during exposure to light and at a mean temperature now raised to 47°·38 Fahr., *thirteen* in No. 1 H were developed in about one-half the space of time from a similar number of eggs removed from the light, and at a mean temperature of 59°·5 Fahr.; so that we seem here to have good reason to believe that a low temperature of the medium not only retards the development of the embryo, even when exposed to light, but injuriously affects the fecundation of the ovum.

The result of the next experiment coincides with the above.

No. 2. P.M. $1^h\ 56^m$.—*Fifty-one ova* were touched in the same way with spermatozoa from the filter paper, as in No. 2 H, and were retained in the same temperature as the preceding.

A few of the yelks became ovoid in about *six hours*, but segmentation did not commence until *seven hours and two minutes*, and then only in a very few. *Two embryos* only were produced from this set.

No. 3. P.M. $2^h\ 5^m$.—*Fifty-five ova* were bathed with filtered fluid in exactly the same way as in No. 3 H; but not a single ovum became segmented. Not one produced an embryo.

Thus while segmentation took place in No. 1 H, in three hours and fifty-six minutes, when the temperature was rising from 59° Fahr. to 64° Fahr., it did not occur in No. 1 I, until seven hours and forty-five minutes, when the temperature during the interval was sinking from 48° Fahr. to 47° Fahr. This sufficiently marks the great influence of temperature during the earliest periods of change in the ovum; and this injurious effect of reduction of temperature at that period is further shown in the relative number of embryos in these comparative experiments. That the injurious effect of reduced temperature at the time of impregnation is mainly the cause of this result, and not the diminution of temperature after the period of impregnation, seems to be shown in the circumstance, that while at the end of the eighteenth hour the ova in the set H had already passed through all the stages of segmentation, and the surface of the yelk had become granulated, and the blastoderma had begun to be formed even although the temperature in that case subsided a little after segmentation had commenced,—from 59° to 57°,—the corresponding set of ova, No. 1 I, had advanced only to the octuple division of the yelk. A similar difference in the rate of development we have seen takes place in the growth of the embryo. At the end of three days the embryos of set H were advanced to the stage at which the laminæ dorsales are proceeding rapidly to meet, and form the median dorsal sulcus of the growing body. But the corresponding ova in set I had not been carried further than to the earliest perceptible indications of the *area germinativa.*

These facts sufficiently prove the great influence of temperature on the development of the embryo in its earliest stages, as the comparative numerical results do also its effects on the impregnation of the ovum. Out of eighteen ova placed in the higher and increasing temperature, thirteen produced embryos at nearly similar stages of growth; while of nineteen ova maintained in a low and diminishing temperature only eight became segmented, and but three of them arrived at the tadpole state.

A somewhat similar but more marked result took place with the ova of No. 2 in the two sets of experiments. The impregnating means employed in these trials had already been forty minutes mixed with water on the filter. Out of forty-eight ova employed in set H, twenty-five became segmented, and ten of these produced young. But in set I fifty-one ova gave birth to only two embryos.

In the third experiment of each set the difference is as strongly marked. As the filtered fluid employed in both was the same, and the very few spermatozoa contained in it were by the same means brought into contact with the ova in each, it might have been expected that each would have produced embryos. But while the production of a single tadpole in the one case, at a high temperature, may be looked upon as leading to the inference that these bodies are the efficient agents in impregnation, the entire absence of all appearance of impregnation in the ova of the other set, to which the same fluid had been equally applied, seems to point to the cause of failure in this case as depending on the prejudicial effect of a low temperature of the surrounding medium on their agency.

The temperature of the surrounding medium ought, therefore, always to be borne in mind when we are attempting to deduce conclusions from experiment on impregnation and development. The presence of light appears to be only of secondary consideration as compared with heat; since in set H, from which light was carefully excluded, not only did impregnation take place more certainly and rapidly than in set I which were exposed to light, but the embryos also were produced in greater number, and acquired maturity in less than one-half the space of time than in the latter; the only difference of circumstance between the two sets being degree of temperature.

Influence of Aëration.—Next in importance to heat is a free *aëration* of the ovum. This is of less consequence with reference to impregnation than to the subsequent production of the embryo. In every set of experiments there are always some ova more advanced than others. These are ova which have been nearest to the surface of the water, and which, consequently, have been more completely aërated as well as exposed to a slightly higher temperature than others at a greater depth. It is from this cause chiefly that the results of experiments on artificial impregnation, and even of observations on naturally impregnated ova, are always less complete and successful than what takes place with regard to the ova in the natural haunts of the species. The ova in a state of nature are usually deposited in well-aërated places, clear, slow-moving water, or shallow and but slightly turbid water. It is almost impossible to afford to ova that are the subjects of experiment, either in broad flat dishes, or in glass vessels in one's study, the amount of aëration required to ensure complete success. By too frequently changing the water in the vessels the embryos often become injured; while if the water be not changed, development is arrested, and decomposition commences, and the experiment entirely fails. Even when these difficulties are obviated by a gentle withdrawal of the water, and a renewal of it with equal care, the perfect stillness of the fluid in the interval of our observations does not allow of that extent of aëration to the embryo which it gains in a perfectly natural state, either in slow-moving waters, where I have usually found the eggs deposited, or in pools of still water, the surface of which is agitated by currents of air, and affected by diurnal changes of temperature.

Thus then we may conclude that the procreative force of the germ, and of the impregnating fluid, is augmented by increase of heat, but the duration of the force is lessened. It becomes less and less energetic in proportion as the temperature is diminished, but the period during which it is capable of being exerted is extended. In each of these conditions aëration is of essential consequence, and becomes more and more necessary in proportion to the increase of heat.

4. THE AGENCY OF THE SPERMATOZOA IN IMPREGNATION.

It is evident from the last-mentioned experiments, that however great may be the influence of temperature in accelerating or retarding impregnation and development, and however much the operation of this influence may be interfered with by want of proper aëration of the ovum, the impregnating force does not equally pertain to all parts of the seminal fluid, but is to be found in some only of its constituents. Experiments made before those now detailed,—and to which I had been led by a conviction that the opinion formerly entertained, that impregnation is effected through means of the fluid portion only of the semen, was not in accordance with facts I had very long been acquainted with in the Articulata,—convinced me that the spermatozoa themselves, and not the other constituents of the semen, are the efficient agents of impregnation. Leewenhoek, and, as I have since found, Prevost and Dumas, not only believed this to be the fact, but also held the opinion that the spermatozoa penetrate bodily into the ovum; and this view has been more recently insisted on by Dr. Martin Barry, with the additional belief that a perforation or fissure exists in the envelopes of the ovum, through which the spermatozoon enters. On careful examination of the envelopes of the ovum of the Frog, I have not been able to detect any fissure or orifice. The question of the agency of the spermatozoa, nevertheless, appears to be capable of solution, however difficult it may be to ascertain the mode and particular nature of such agency. The separation, as far as possible, of the spermatozoa, by filtration from the fluid in which they move, and testing the ova with these and the fluid separately, afford good proof of the agency of these bodies; while immersion of the ova in coloured fluids, at the moment of their passage from the body of the frog, seems equally fitted to ascertain the believed existence of a fissure or perforation through the envelopes during their expansion. The experiment of filtration was originally performed by Prevost and Dumas with well-marked results, and it has since been repeated by the first of these observers* by a different mode, —endosmose through the operation of galvanic currents. The mode pursued by myself was that originally adopted by these observers:—careful mechanical filtration, by simply passing the fluid portion of diluted semen through folds of filtering-paper. The paper I have employed, and which alone was fitted for the purpose, was the best Swedish filtering-paper employed by chemists in their most delicate analyses. A large proportion of the spermatozoa were always retained, even on a single filter, although a few usually passed through; but this, as the results show, was not in reality a disadvantage, when a few only were present in the filtered portion. When three or four folds of filtering-paper were employed, the whole of the spermatozoa were removed.

Filtration of Seminal Fluid.—Fluid obtained from a male frog, immediately after removal from the female, was mixed with about twice its quantity of water and placed on the filter. Portions of this fluid as they passed through were repeatedly examined with the microscope. Some of these filtered specimens contained a very few spermatozoa, usually not more than three or four in the drop examined, but sufficient occasionally, as the results proved, to effect impregnation.

Filtration Experiments.—Set K. March 14, 1849. Atmosphere 55°·5 Fahr. Water 55° Fahr.

No. 1. A *single drop* of the *filtered fluid* was added to one ounce of water, in which *forty-six ova* were immersed. Not a single egg became segmented or produced an embryo.

No. 2. A *single drop* of the diluted fluid, *not filtered*, but two hours after it had been obtained, was added to one ounce of water with *ninety ova*. Not a single egg was segmented or produced an embryo.

No. 3. *Two drops* of *filtered fluid* were added to one ounce of water with *sixty ova*, but not one egg became impregnated.

No. 4. *Three drops* of *filtered fluid* were added to one ounce of water with *one hundred and five ova*. *Two* of these were partially impregnated, as shown by their becoming imperfectly segmented (Plate XIV. fig. 11 and 12), but neither of them produced an embryo.

No. 5. *Three drops* of diluted fluid, *not filtered*, but two hours after being mixed with water, were added to one ounce of water with *seventy-six ova*. Several of these became segmented, but more tardily than in the following experiment, No. 7. At the end of seventeen days *fifteen* embryos had been produced from these ova.

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* Journal de l'Institut, 1840, No. 362, p. 908.

No. 6. *Thirty drops* of *filtered fluid* were added to one ounce of water with *two hundred and ten ova.* At the expiration of five hours two ova had become segmented, and two embryos were afterwards produced.

No. 7. *Thirty drops* of diluted fluid, *not filtered,* were added to water with *two hundred and fifty ova.* At *four hours and forty-two minutes* segmentation had commenced in two or three of these, and in *five hours* had occurred in almost every ovum. Nearly the whole of these produced embryos.

No. 8. About *thirty drops* of the same diluted fluid, *not filtered,* were added to water that contained about *two hundred ova,* passed from the body of a frog killed twenty hours before. A few of these ova became imperfectly segmented, but not one produced an embryo.

From these first experiments with filtered fluid, it seemed that the portion of semen which passes through the filter has not the power of impregnating, unless there are spermatozoa present in it; while similar quantities of diluted semen that has not been filtered, are efficient and impregnate, as in Nos. 4, 5, 6 and 7. Further, it is shown, from No. 8, if we may judge from one experiment, that ova which have remained in the body of a frog twenty hours after actual death and cessation of the organic functions, and in a temperature of 55° Fahr., may be affected by the stimulus of the impregnating fluid, but not sufficiently so perhaps as to result in fruitful impregnation.

During the time these ova were under observation, in March 1849, an opportunity occurred of observing the effect of reduced temperature on the rate of development of the embryo when its formation has been somewhat advanced. On the seventh, eighth and ninth days after impregnation of the ovum, and when the temperature had already been considerably reduced, the season became severe, and in order to test the effects of cold, the eggs were removed to the open air and exposed to a keen wind. The temperature of the atmosphere was then 38° Fahr. During the night of the tenth day, the water in which the ova were contained was frozen to a mass of ice. Yet many of these ova, as above shown, produced embryos. Spallanzani had already remarked, that the eggs of the Frog may be inclosed in ice, and yet afterwards produce embryos, if the envelope does not become frozen*.

The experiments made to ascertain whether cleavage of the yelk may be taken as a test of impregnation (p. 190), seemed also to show that, *within certain limits,* a large or small quantity of seminal fluid has some influence on the more or less early occurrence of this phenomenon. It occurred to me, therefore, that in making the experiments now given, two questions might be examined: one, as to whether the extremely minute quantities of seminal fluid disseminated in water, as mentioned by Spallanzani, are as efficient to produce the embryo at the low temperature of the season at which the Frog spawns in this country, as in the warmer region of Italy; and the other, whether the presumed efficiency of such minute quantities depended on the presence of the spermatozoa; and it seemed possible to put these questions to the test in one set of experiments. But, in attempting to do so, it was a matter of importance, first, to obtain some approximative knowledge of the actual quantity of spermatic fluid employed by Spallanzani, in his more remarkable experiments, to enable me to compare the results of my observations with those of his. Spallanzani states, that by his mode of obtaining the seminal fluid, by vivisection, he could only procure from "two to three grains*" from each individual. Three *grains* weight of fluid are equal, by measure, to nearly three *minims* of our medicinal standard. But it may be presumed that in so delicate an operation as that of removing the fluid from the vesiculæ seminales, from which Spallanzani states he usually obtained it, he could rarely be very precise in his determination of the quantity. I assume, therefore, for the sake of comparison, that the quantity he speaks of as "a *grain*" was about equal to a *minim* of our medicinal measure. Three grains of fluid (? minims), he says, were mixed with a *pint and a half* of water, and one *drop* of this mixture (the seminal fluid in which was equal to $\frac{1}{3840}$th part of the whole at 16 oz. per pint) applied directly to an ovum on the point of a needle, was "frequently" sufficient to render it fruitful†. The *drop* spoken of in this experiment was a much less quantity than the grain or minim; indeed, Spallanzani states that it did not exceed the "fiftieth of a line" (? fifth) in diameter. The quantity of fluid obtained by myself from a frog was usually about *six minims*, and this I mixed with twice its quantity of water, thus making eighteen minims. One *drop* of this mixed fluid measured, as I found, one-third of a minim, and consequently contained one-third part of seminal fluid, or one-ninth of a minim of the seminal fluid. Yet the result of the employment of one drop of this mixed fluid added to one ounce of water, in which the proportion of seminal fluid was then made to be $\frac{1}{4320}$th part of the whole, did not lead to the same result as the experiment by Spallanzani. The difference arose, perhaps, from the operation of two or more causes:—first, the much lower temperature of the atmosphere at the time of making my experiment, than at that of Spallanzani's; next, the diminished efficiency of the seminal fluid, owing to the length of time (two hours) it had been removed from the body. Both these circumstances, but especially the first, as already shown, operate unfavourably in experiments on impregnation, more eggs being fertilized at a high temperature, when the changes go on rapidly, and especially when the seminal fluid has been most recently obtained, than under the opposite conditions. The general results of my experiments, however, may be regarded as quite confirmatory of Spallanzani's more remarkable one, as they prove, like that, that only an exceedingly small proportion of seminal fluid is necessary to fertilize the ovum.

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* Dissertations, &c., vol. ii. p. 49.

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[*] *Loc. cit.*, vol. ii. p. 189.

[†] *Loc. cit.*, vol. ii. p. 192. There is some confusion of statement in the translation of Spallanzani's work, now referred to, respecting the quantities mentioned by the author, as "pint" is the word used in some passages and "pound" in others (p. 191), apparently synonymously, while the latter is further spoken of as "twelve ounces."—G. N.

But however satisfactory these experiments were with regard to that fact, they still left the question of the immediate agency of the spermatozoa in impregnation in doubt. I therefore repeated them with greater precision, and with that object only in view, and took especial care to obtain as perfect a filtration and separation of the spermatozoa from the fluid as possible. The results were far more interesting and instructive than I had anticipated, as I found by repeated examination by the microscope that the filtered fluid was almost completely deprived of spermatozoa, one or two only being occasionally detected in it, with a very few nuclei and spermatozoal cells. One circumstance that tended to increase the value of this set of experiments, and to prove the influence of the spermatozoa, was, that the ova employed were not fully matured, and hence I had less expectation of a favourable result. The quantity of seminal fluid obtained was larger than usual, and this was mixed with twice its quantity of water. This mixed fluid was divided, as before, into two portions, one of which was filtered, and the other not. The experiments were commenced in the early part of the day, and the temperature of the atmosphere of the room, and that of the water employed, was nearly the same, 51° Fahr., and the whole of the experiments were placed as nearly as possible under similar circumstances.

Set L. March 18, 1849. Atmosphere 51° Fahr. Water 51° Fahr.

No. 1. *Ten minims* of the mixed fluid were added to two ounces of water, into which *one hundred and fifty ova* were immediately passed. One hour afterwards I found a great abundance of spermatozoa adhering to the surface of the envelopes. Segmentation of the yelk commenced in *five hours and forty minutes* in a few ova; and took place in others at a later period. A few only of these ova produced embryos.

No. 2. *Ten minims* of the filtered portion of the mixed fluid were added to two ounces of water, and about *one hundred and fifty ova* were passed into it. When these ova were examined at the expiration of an hour, not a single spermatozoon was detected on any of them; and when repeatedly examined at the end of five and six hours, not one showed any signs of cleavage. This change did not take place in any of them even at a later period, and *not one produced an embryo.*

As the ova in these two experiments were the first that passed from the body of the Frog, it was fair to regard them as being the most matured; segmentation ought, therefore, if it occurred at all, to have taken place at an earlier period in these than in others afterwards obtained from the same female.

No. 3. *The filter paper* employed in separating the fluid used in the last experiment, No. 2, and which retained the separated spermatozoa in a minute quantity of fluid that had not passed through, was placed in two ounces of water, and *one hundred and thirty ova* from the same female were shed upon it. When some of these ova were examined at the end of an hour and a half, spermatozoa in vast abundance were found adhering to every part of their surface, but the whole were then motionless, and apparently dead and partially coiled on themselves (Plate XIV. fig. 8 *c*). In some of these the body appeared to be slightly enlarged. Segmentation commenced in very many of these ova in *five hours and ten minutes*, and was almost universal in them a few minutes later. *Nearly the whole of these ova produced embryos*, there being only nine out of the one hundred and thirty that were abortive. I have sometimes found a much larger proportional number of unproductive ova in some broods in the natural haunts of the Frog.

There was one exceedingly interesting fact in this experiment,—it was that the smaller and apparently less matured ova were as fully impregnated as the larger and more perfect. The whole set of observations was the more interesting from this circumstance. These ova were smaller than usual and had not the white surface so complete, but were very like the ova in which I have described the changes in the light-coloured surface (p. 185). When first placed in water with the filter paper and spermatozoa, the surface of the yelks became more contracted and irregular, within the vitelline membrane, than in other ova I have employed. Hence I had much doubt, at first, whether any satisfactory evidence would be obtained from this set. But the contrary has been the case, as it is evident that some ova may be impregnated at a little earlier period than usual; and that when a great abundance of spermatozoa is supplied, ova less matured than others may be equally well impregnated. The greater efficiency of a larger as compared with a smaller number of spermatozoa, with reference to the earlier or later segmentation of the yelk, has already been shown; and the difference is very marked in the first and third of this set of experiments, both with reference to the occurrence of segmentation and to the relative fecundity of the ova. On the other hand, the experiment No. 2 proved that the *liquor seminis is not* the fecundating portion of the seminal fluid.

Circumstances having prevented me from making known the result of these experiments at the time they were obtained, I determined, during the past spring, to repeat and vary them, to obtain, if possible, still more conclusive proofs that the spermatozoa alone effect impregnation. Accordingly, in March and April of the present year (1850) I repeated them, with the following precautions:—first, that the frogs in each case had been some days paired, and at the time of the experiment were nearly ready to spawn; next, that the seminal fluid used was obtained from the male paired with the female from which the eggs were taken; further, that the condition of the specimen of fluid used was correctly ascertained; and lastly, that the ova were placed in flat dishes, under precisely similar circumstances, with similar quantities of water, repeatedly changed. Two sets of experiments were made at the same time.

Set M. April 4, 1850. Atmosphere 60° Fahr.

The seminal fluid employed, mixed with an equal quantity of water, was placed on a *single*, and caught on a double filter paper, and the clear fluid that passed was then examined with the microscope. The fluid that had traversed the three filters was almost completely deprived of spermatozoa; as, after many very careful examinations, both of drops as they passed the last filter, and of portions from the capsule it was caught in, there was only one instance of the presence of spermatozoa. In this I saw *two*, but perfectly motionless. The fluid that passed through the *first* or top filter, I had reason to suspect was contaminated by a small quantity having travelled over the sides of the filter. I knew also, that a few spermatozoa always penetrate through a single filter, or rather perhaps are carried through by the fluid. Accordingly, I detected several spermatozoa in this portion. The fluid that remained in the interior of this filter abounded with very active ones. It was not employed until fifty-three minutes after it had been procured from the Frog.

No. 1. *Seventy ova* were passed on a dry surface, and a portion of the fluid which had traversed three filters was poured carefully over them, and water was then added.

In *four hours and twenty-five minutes* I found *one ovum* partially impregnated, and the yelks of others were somewhat shrunk, and a little irregular, an appearance frequently seen in ova that have not been impregnated. Not a single ovum, however, was fruitful.

No. 2. *One hundred and twenty-seven ova* were shed into water on the second of the three filters, which still retained a portion of the fluid from the first, and in which I had found a few spermatozoa. At *four hours and fifty minutes* several of the ova had begun to be divided, and out of this set of eggs *sixteen embryos* were produced.

No. 3. *One hundred and sixty-three ova* were passed into water on the topmost of the three filters, and *four hours and fifty minutes afterwards* a very large proportion of them had become segmented, as was expected, although from the circumstance of the seminal fluid having been more than one hour mixed with water before it was employed, the number was not so great as usual. But it was not entirely due to this cause. Many of the ova had been injured before impregnation, and these became irregular and pear-shaped. At the end of twelve days *forty-nine* well-developed embryos had been formed.

Set N. April 4, 1850.

Four filters were now used instead of three, the seminal fluid being obtained and mixed as before. The fluid which had passed through the whole of these filters, contained not a trace of spermatozoa or of the nuclei of cells. That which had passed through two only still gave an occasional perfectly motionless spermatozoon, but not a single one in motion; the fluid from the uppermost or first filter, as in *Set* M, still swarmed with myriads of active spermatozoa. It was thus proved that the filtration was complete.

No. 1. *One hundred and thirty-one ova* were passed on a dry surface, and a portion of the fluid which had traversed the four filters was poured over them, and water was then added. But not a single ovum gave any sign of having been impregnated, not one became segmented, nor was a single embryo produced. The ova became slightly irregular, shrunken, and depressed at parts of the yelk, a condition which, as I had noticed this in other ova, I was inclined to attribute to some normal change in the yelk itself, perhaps of an imbibing or endosmic character.

No. 2. *One hundred and ninety-seven ova* were shed into water mixed with the remaining portion of fluid which had passed through the four filters, but not a single egg gave even a trace of segmentation. Many of the yelks had the same peculiarly irregular outline as in No. 1. These two experiments I regarded as a satisfactory proof that it is not the fluid portion of the semen which impregnates.

No. 3. *Two hundred and four ova* were passed into water upon the third filter, already immersed in it, and the fluid on which showed an occasional spermatozoon. I was unable to detect any impregnated ova in this experiment, but, as the result showed, a few had been affected, as *four embryos* were produced.

No. 4. *Three hundred and seventy-one ova* were passed into water upon the first or topmost of the four filters, and which had already been placed in the water. At *four hours and thirty minutes*, almost every yelk had become segmented. The change had occurred some length of time before this, as the second or crucial segmentation was commenced. This experiment seemed to be a most direct and conclusive proof of the agency of the spermatozoa. At the end of four days almost the whole of the eggs were producing embryos, many of which were advanced to the *fourth period of development*. *One hundred and twenty-seven* became fully formed and vigorous, besides nearly as many more which did not complete their changes, from an accidental cause.

Before these concluding experiments were made, I had already, in March last, repeated the preceding; but, as the filtration was less perfect, have thought it unnecessary to give them in detail; they agreed however in the results. The whole have confirmed in the fullest manner the experiments first made, and have proved, as I trust, satisfactorily that the spermatozoa alone are those parts of the semen which effect the impregnation of the ovum. Having repeated the filtration in five separate sets of experiments, on different occasions, and with exactly the same general results, I can no longer entertain any doubt of the direct agency of the spermatozoa. The conclusion, I think, is rendered certain by facts now shown, which escaped the notice of SPALLANZANI, and of PREVOST and DUMAS. Segmentation of the yelk takes place earlier when impregnation is effected by a large, than when occasioned by a very small number of spermatozoa, the temperature of the surrounding medium, and all other circumstances, being alike in the two cases, as in the experiments *Set* A as compared with *Set* B (p. 190). This fact is supported by another, equally significant. When only a very small number of spermatozoa exist in the fluid, then the remarkable result of partial impregnation often takes place, and the ova are unproductive. On the other hand, when spermatozoa are supplied in full abundance to the ova, not only does segmentation of the yelks take place more rapidly, but also more extensively, and almost every ovum produces an embryo.

With regard to the liquor seminis, it seems equally decisive that this portion of the seminal fluid *does not* effect impregnation. Wagner and Leuckardt[*] have justly remarked, that it is almost impossible that the *liquor seminis* can have any action on ova which are expelled into water before the semen is ejected by the male, as in the case of frogs and fishes; and it is worthy of note, that in the experiments now detailed not a single ovum was either *completely* or *partially* impregnated when immersed in water mixed only with the liquor seminis, obtained through filtration; nor even when the ova were carefully bathed, as they passed from the body of the Frog, and before they had been brought into contact with water, with the filtered fluid from which the spermatozoa had been completely separated, as in *Set* N, No. 1, or even when the fluid still contained a very few dead and perfectly motionless spermatozoa. Yet this fluid can hardly be regarded as entirely without use, although it now appears to be of very secondary consequence. When the ova were placed in water with which only the *liquor seminis* had been mixed, the yelks became contracted exactly as is often the case in the unimpregnated ovum. Whatever may be the nature of this fluid, it does not appear to be essential to the conveyance of the structural peculiarities of the male parent to the offspring. These appear to be communicated by the spermatozoa alone, as not only did the ova that were impregnated by spermatozoa from the filter paper, as in *Set* N, No. 4, become segmented quickly, but the embryos produced from them came forth with all the usual characters of tadpoles, and have passed, or are now passing (June 20) through their stages of growth as perfectly and as quickly as others which have been produced in the natural haunts of the species through the mutual concurrence of both sexes. Thus the liquor seminis does not even hasten the course of development of the young. Neither does it accelerate that of fecundation, either through direct imbibition or from becoming a solvent to the bodies of the spermatozoa; as we have seen that segmentation of the yelk takes place most quickly in proportion to the number of spermatozoa, within certain limits, in contact with the ovum. And such also is the case in a state of nature.

These facts appear to give that *direct negative* and refutation to the hypothesis of the immediate agency of the liquor seminis in impregnation which Wagner and Leuckardt[†] remark it has not hitherto met with; and they lead to the supposition that one of the chief uses of the fluid is merely that of a vehicle through which the spermatozoa are more readily brought into contact with the ova. Possibly it may bear that relation to the spermatozoa in the viviparous vertebrata, in which it chiefly occurs, which the fluid medium into which the ova of Amphibia and Fishes are expelled, bears to the spermatozoa in those classes. This view may derive some support from the fact that the liquor seminis has recently been shown by chemical analysis to consist chiefly of a thin solution of mucus, with small quantities of chloride of sodium and phosphates and sulphates of the alkalies[‡].

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[*] Cyclopædia of Anatomy and Physiology, vol. iv. "Semen," part xxxiv. January 1849, p. 507.

[†] *Loc. cit.*, p. 507.

[‡] *Id.*

5. NATURE OF THE AGENCY OF THE SPERMATOZOA.

Having obtained full evidence by direct experiment that impregnation is effected through means of the spermatozoa, we have now to inquire as to the manner in which it is induced by them, and as to the nature of the agency they exert. Spermatozoa have been found adhering to the surface of the impregnated ovum by Barry, Bischoff, Pouchet and others, in the Mammalia; as they were long ago seen by Prevost and Dumas on the ovum of the Amphibia; and since by Siebold, Kölliker, myself and others in the Invertebrata. They have been constantly present in those experiments on artificial impregnation which I have now detailed, in which the yelks became segmented after the egg had been in contact with seminal fluid, or with the filter paper used to remove them from the liquor sanguinis; but they have not been detected on ova which did not undergo the cleavage of the yelk, or which had been immersed only in fluid separated during filtration. Whenever present in fluid in which ova have become impregnated, the spermatozoa have always been found in motion, until after they have become attached to the surface of the ovum, when their motion has soon ceased. In the *Lissotritons*, in the few experiments I have made on this division of the Amphibia, I have seen the motion continue for a long time after they have been in contact with ova. This leads to the supposition that a vibratile condition or power of motion is in some way essential to their power to effect impregnation; notwithstanding that, as Wagner and Leuckardt have remarked*, no movements have as yet been perceived in the spermatozoa of the *Isopoda* and *Amphipoda*. If this vibratile condition be essential to their function, then the length of time which it is continued may be of importance.

Duration of Motive Power in Spermatozoa.—Spallanzani found that water mixed with but a small quantity of seminal fluid of the Frog retained the property of impregnating ova longer than pure semen†. When inclosed in a glass tube, the semen of the Toad was not impaired at the end of six hours, but was useless at the end of nine‡; while a small quantity from the Frog, mixed with water and preserved at a temperature of about 40° Fahr.§, was still efficient at the end of thirty-five hours. Results obtained by myself have fallen short of this extended period, even when the influence of temperature has been attended to. The difference of result may to some extent be accounted for in the condition of the fluid, and in the way in which it has been obtained. Spallanzani says he obtained it both from the vesiculæ seminales and the testes after opening the body. It is probable therefore that a large part of what he procured had not arrived at maturity, and instead of consisting almost entirely of active spermatozoa, as when it is obtained by compression of the body, the mode adopted in my experiments, it included a large proportion of developmental cells from which the spermatozoa escaped at longer or shorter periods after the fluid had been mixed with water, or had been retained for some time out of the body. I have very rarely found the seminal fluid of *Rana temporaria* obtained in the way stated, and at a temperature of about 50° Fahr., retain any impregnating influence for more than four or five hours. Thus, after mixing it with an equal proportion of water, very many of the spermatozoa have soon become motionless, and in less than two hours a moderate proportion only have continued active. At three hours there have been still fewer moving; while at four hours the great majority of them have exhibited most unequivocal signs of lost vitality, being either extended at length or coiled on themselves (Plate XIV. fig. 8 *c*), as they usually appear when motionless, and adherent to the surface of ova. If any, at this length of time, have been still moving in the fluid, they have been few in number, and their motions exceedingly feeble. Occasionally I have detected others, at this lapse of time, in the act of escaping from the cells (fig. 8 *a* and *b*), and these have always been the most energetic in their movements immediately after their liberation. Further, I have noticed that in those specimens of fluid which have contained most developmental cells, the spermatozoa have been longest in a state of activity.

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* *Loc. cit.*, p. 503.

† Dissertations, vol. ii. p. 193.

‡ *Id.* p. 168.

§ It may be well here to mention, that for the purpose of more easily comparing the observations recorded by Spallanzani, and Prevost and Dumas, with the results obtained by myself, I have, throughout this paper, reduced the data given by them to the scale of Fahrenheit, employed by myself; the scale used by Spallanzani being that of Reaumur, and by Prevost and Dumas the Centigrade.

The following have been the results of observations on spermatozoa attached to the surface of ova, or contained in the water in which ova were immersed. At *three-quarters of an hour* after mixing *recently obtained* seminal fluid with the water and ova, vibratile spermatozoa have continued to be exceedingly abundant and in a state of great activity. *At one hour and a quarter* there were still an abundance in motion, but many were now perfectly motionless, and apparently dead. At *one hour and a half* I was not able to detect any movement in even a single spermatozoon out of a vast abundance which adhered to the surface of the gelatinous coverings of the ova, although I sought for this very carefully. Neither could I detect even the slightest indication of the spermatozoa having penetrated into these coverings, either near the surface or in the vicinity of the thicker envelope, which I regard as the *chorion*, and which immediately covers the *vitelline membrane*. After a lapse of some time all the appearance of spermatozoa on the exterior of the envelopes ceased. The longest period, after contact with spermatic fluid in water, at which I have hitherto been able to recognize these bodies on the surface of the frog's egg has been *six hours and one or two minutes*, and about half an hour after segmentation of the yelk had commenced. This was on ova impregnated artificially, on the 14th of March, at a temperature of the atmosphere of the room of 54°·5 Fahr. and 53°·5 of the water employed. A few motionless spermatozoa were then still found on the surface, but most of them appeared to be becoming disintegrated. The surface of the egg-envelope was then covered at places with numerous small granules, possibly the remains of spermatozoa which had disappeared.

A somewhat similar result has ensued when spermatozoa have been *two hours* mixed with water before ova were passed into it. At *five minutes* after immersion of these ova, I have found large quantities of spermatozoa already adhering to the surface of their then expanding envelopes. But many of them have already been coiled on themselves, and were perfectly motionless. The water still contained very many disseminated through every part of it, but most of them, with few exceptions, have appeared to be rigid, and to have become enlarged in diameter, but not increased in length. This change has appeared to be due to the hygroscopic nature of these bodies, as formerly pointed out by SIEBOLD*. Possibly this nature may have some reference to impregnation. Repeated observations lead me to believe that, in whatever way the spermatozoa are concerned in impregnation, they do not penetrate bodily into the ovum, but merely adhere to the surface.

PREVOST and DUMAS concluded† from their investigations, that the spermatozoa of the Triton and Frog do penetrate into the envelope of the egg; and they state that they had fecundated ova taken from the ducts of the Triton, and after the lapse of three hours, having first carefully washed them to remove all that were merely adhering to the surface, have made sections of the envelopes of the egg, and, with the aid of the microscope, have found living spermatozoa still struggling within. Their words are—"Une grande quantité d'animalcules encore mouvans, et qui semblaient se débattre dans cette espèce de gelée où ils se trouvaient emprisonnés. On en voyait partout même au contact des membranes de l'œuf." Further, that they had repeated this experiment on the ova of the Frog, and found the envelope penetrated in like manner with spermatozoa, still moving, but not changing place. I regret much that my investigations do not enable me to confirm these observations, which seem to me to be due to the circumstance of these physiologists having regarded the objects on the surface as being in the interior. I have many times sought for spermatozoa within the substance of the egg-envelope of the Frog, at different periods between that of first contact with impregnating fluid and the time when cleavage of the yelk has commenced, and have constantly found them on the surface, but have never, even in a single instance, observed any appearance of them in the substance of the envelope, nor anything which induced me to suspect that they penetrate bodily into it. They have been present on the surface, and adherent to it, even from within a few seconds after contact, to so late as the sixth hour, but have usually been motionless; and most of them have had the caudal portion folded back on the body. I was led to make these observations on the egg of the Frog,—before I was aware of MM. PREVOST and DUMAS' views,—from the circumstance of Dr. MARTIN BARRY having mentioned‡ that an orifice or fissure exists in the thick investing membrane of the ovum of the Rabbit, through which, at the time of impregnation, he believed the spermatozoon to enter. All the observations I have been able to make on the ovum of the Frog, both microscopically and experimentally, are opposed to the belief in the existence of any perforation either before or at the time of impregnation. With regard to the ovum of the Tritons, I have recently made the following observations, since becoming acquainted with the views of the authors named.

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* MÜLLER's Archiv, 1836.

† *Loc. cit.*, vol. ii. p. 133.

‡ Philosophical Transactions, 1840, p. 535.

A female *Lissotriton punctatus*, obtained on the 17th of May, produced several ova on the morning of the 19th. Cleavage of the yelk (which, I may remark, was entirely overlooked by RUSCONI* in his account of the Newts) commenced in two of these ova at the expiration of eight hours, the temperature during the period having ranged from 56° FAHR. to 62° FAHR. On examining these ova very carefully about an hour before the cleavage commenced, there were what I regarded as portions of the bodies of spermatozoa on the surface, but certainly no traces of any in the interior. While engaged in this examination the same female produced another egg, which she inclosed as usual in a folded leaf. On this specimen, examined at the end of half an hour, I could not detect any spermatozoa on the surface, which led me to imagine that it had not been impregnated, a supposition which ultimately proved to be correct, as no segmentation of the yelk took place in it. Some time after this, the temperature of the atmosphere being 62° FAHR., I saw the same newt enclosing another egg in a leaf. This I immediately removed for examination, and thinking that this, like the previously deposited egg, had not been impregnated, no traces of spermatozoa being found on its surface, I placed it for about a minute in a small capsule filled with water, into which a quantity of fluid had just been expressed from a male that had been kept separate from the female. The fluid on examination was found to be composed almost entirely of very active spermatozoa. The egg was examined three minutes after immersion, and scarcely five minutes after it had been laid, and multitudes of spermatozoa were then seen adhering to its surface. Most of them were still vibrating rapidly, while others were motionless. But although I was able to distinguish every part of these bodies, I could not detect any in the act of penetrating, or which had already penetrated into the substance of the envelope, and most certainly not one was imbedded in the interior. Neither were there any in contact with the yelk-membrane, or in the yelk-chamber of the envelope.

The egg of the Newt is peculiarly fitted for an examination of this kind, from the fact of the existence of this yelk-chamber, or space in the interior of the envelope. This is formed by the gelatinous covering which the egg gains in the oviduct imbibing fluid by endosmose and becoming expanded immediately it comes into contact with water, when the inner layer separates from the vitellary membrane, with which it has been in contact within the duct; and as the outer layers more and more expand, the yelk, covered only by the vitellary membrane, is left free in a large cavity in the interior, surrounded by a thin fluid. The spermatozoa of the Newts, as is well known, are of large size, and are easily recognized; so that in the event of their having penetrated the egg-covering before it leaves the duct, or at the moment of its expansion, or after the chamber has been formed in it, they can hardly escape observation.

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* Amours des Salamandres Aquatiques, 4to. Milan, 1821.

I preserved this egg confined to one spot in a minute glass capsule, and in exactly the same position beneath the microscope, for forty-eight hours. During the first three quarters of an hour many of the spermatozoa on its surface exhibited as vivid motions as at first, but still adhered to the same parts, and had not, so far as I could perceive, changed their posture or their place in the least, or had penetrated in the slightest degree into the envelope. At the end of twelve hours I found that the yelk had undergone the usual process of cleavage, which, at that time, had already been advanced to the stage of coarse granulation of the surface, a fact which proved most distinctly that this egg had been impregnated. Spermatozoa were still distinctly recognized over the whole surface of the envelope, but their motions had now ceased. On the following morning, May 20th, the changes were found to have proceeded uninterruptedly, as the yelk was then finely granulated over its whole surface. At a little later period, the *end of twenty-four hours,* a few spermatozoa were still adhering to the surface of the envelope, but the whole were perfectly motionless, and many had evidently disappeared. Still, not one could be detected in the substance or in the chamber of the envelope. At *twenty-eight hours* the granulation of the yelk was nearly completed, and its surface was becoming smooth, and there were still a very few motionless spermatozoa on the exterior of the envelope. At the end of *forty-eight hours,* May 21st, I was still able to recognize the bodies of several spermatozoa which had not yet disappeared, but which had become very indistinct, as if in a state of diffluence. At the end of *sixty hours* I could no longer detect any trace of them. The egg that was the subject of these observations proceeded regularly in its changes, and ultimately produced the embryo; all the stages of which I have traced and delineated for future communication to the Royal Society.

Subsequently to these observations I saw ova passed by another female, *Lissotriton palmipes,* and on submitting these to the same close examination as the above, within five minutes after their production, I again found what I regarded as the remains of spermatozoa on the surface of the egg-covering, but not a trace of any in the interior or in the vicinity of the yelk.

Endosmosis of the envelopes during impregnation.—But although the facts now mentioned are so opposed to the view that the spermatozoa penetrate bodily into the ovum, it is due to the distinguished observers to whom I have referred to enter somewhat more fully into the questions which their observations involve; and while I am free to admit the possibility of mistake or oversight on my part, to mention the details of some experiments made expressly with the view to ascertain whether the envelopes of the ovum of the Frog are permeable in any part to solid particles of matter; or whether there exists any orifice in them by which such particles can enter. It is well known that during the transit of the ovum through the oviduct the vitellary membrane becomes invested with a thick gelatinous covering, the first thick layer of which may be regarded as the rudimentary *chorion,* and perhaps may be analogous in its function, in some respects, as it seems to be in its place and mode of origin, to the albuminous investment of the ovum of the Rabbit. I cannot, with Rusconi[*], regard this envelope of the Frog's egg as being merely a mechanical protection during the process of development. It is formed of cells with distinct nuclei, and from what I shall presently mention, seems to be essential to the ovum at the commencement of the changes, and to be intimately connected with the act of impregnation. Rusconi deprived the ova of the green aquatic frog, ? *Rana esculenta*, of their gelatinous envelopes at a period subsequent to impregnation, and found that they passed through their changes as well as when covered by them; and he thence concluded that the envelope is of no use further than to protect the egg from the injury it might receive through mechanical disturbance, "des petits chocs qui pourroient nuire à son developpement[†]." Certainly it affords this protection to the germ, but to conclude that this is its sole office appears to be somewhat premature. I have found that it is almost impossible to remove this envelope from the Frog's egg at the moment of deposition, or even during the first few minutes after submersion, and before it has become expanded by imbibition of fluid; although it may be removed without much difficulty from the egg of the Newt, the yelk of which, in the vitelline membrane, lies free and unattached in its interior. But some time after the expansion has taken place I have myself found that the frog's egg may be deprived of a large portion of this covering, and yet produce an embryo equally well as if it had remained protected. On the other hand, one most important function of this investment seems to be indicated in the following facts. Spallanzani found that ova of the Frog deprived of their envelopes before contact with the male influence, were not impregnated; and further, that ova taken directly from the ovaria, are not susceptible of impregnation[‡].

A remarkable fact which I noticed, at a time when I was not fully aware of its interest and importance, enables me to confirm this observation. I captured a pair of frogs, the female of which, a short time after they were in my possession, had a large hernia formed by a protrusion of part of the great oviduct through an accidental wound in the posterior part of the right side of the body, and in consequence of which she was unable to deposit her ova. This wound had been received before the union of the sexes, but the hernia was formed afterwards, during the passing of the ova from the ovaria. The result of this was, that when some of the ova had passed into that part of the duct which protruded through the wound, the sac formed by it was constricted, and became so enlarged by the expansion of the egg-envelopes, that the remainder of the ova were prevented from entering it. On opening the abdomen of the frog after death, I found that a very large proportion of the ova which had left the ovarium on that side of the body, were lying in the cavity of the peritonæum, among the viscera, being entirely prevented from entering the duct, which was filled throughout its whole extent, to its very orifice, with eggs which had already entered, and were prevented from passing on. On the left side of the body the ova had also quitted the ovarium, but the whole on that side had passed into the oviduct in the usual way. The eggs found in the cavity of the body consisted only of yelk-masses in their vitelline membranes. I immediately placed some of these eggs in water, with seminal fluid obtained from the male with which this female had been paired; but not a single egg became impregnated, or gave afterwards any sign of formation of the embryo. I had some hesitation in regarding this experiment as quite conclusive,—that impregnation cannot take place before the egg has gained its gelatinous envelope, and consequently while it is still within, or has but just escaped from the ovary,—from the possibility that these eggs might have been for some time in the cavity of the body, and that some change might have been induced in them through long detention. In so far, however, as that this was in accordance with SPALLANZANI's experiment, it seemed to point to the nature and importance of the covering which the egg gains in the oviduct.

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[*] *Loc. cit.*, p. 8.

[†] *Loc. cit.*, p. 9.

[‡] Dissertations, &c., ii. 152, 3.

Since my attention has been more particularly directed to this point of investigation, I have repeated the experiment on the ova of the Newt, *Lissotriton palmipes*, with precisely similar results. I opened the body of a female with great care (after dividing the spinal cord through the medulla oblongata), for the purpose of obtaining ova from the oviducts, for artificial impregnation, and immediately saw that a number of ova were free in the cavity of the abdomen, and were in the course of being transferred to the entrance of the tubes, as stated in the first part of this paper. These ova, like those which had recently escaped from the ovarium in the Frog, were without any other covering than their vitelline membranes; most certainly I was unable to detect any other, and they were so delicate that it was with difficulty they were removed into water to which fluid from the male had been added. But although uninjured in the removal, and in every way carefully treated, not one gave any sign of cleavage of the yelk, which, as I have before stated, I have constantly found take place in the impregnated ova of newts as well as of frogs, although the fact of its occurrence was overlooked by RUSCONI; not one egg afterwards produced the embryo. Thus then it seems fair to conclude that the egg in the *Amphibia* is not fitted for impregnation until after it has entered the oviduct and acquired its gelatinous covering.

I have already shown that there is a remarkable coincidence between the rate of expansion of the gelatinous covering, immediately after the egg is placed in water, and the susceptibility of the egg to become impregnated; and that in proportion as the covering becomes enlarged and distended by imbibition of water, the susceptibility of the egg becomes diminished; until at the end of about half an hour it is almost completely lost, at which time the rate of expansion of the envelope is also greatly lessened, and the envelope itself has attained to more than two-thirds its future diameter. Now SPALLANZANI found that the susceptibility of the ovum, when immersed in water, had ceased at the end of fifteen minutes, at which time the envelope is considerably enlarged. PREVOST and DUMAS also observed that the expansion of the envelope is greatest during the first three hours, and rightly regarded the occurrence as connected with impregnation, and with this opinion made experiments to test their views. They placed ova taken from the oviducts in ink, and found the envelopes blackened with the imbibed fluid*; but they remark—"bientôt cette imbibition s'est arrêtée à cause de la reaction chimique de l'encre qui coagulait la matière muqueuse." Afterwards they employed the blood of the Frog mixed with water, and found the envelope deeply reddened when immersed in it; and thence concluded that the envelope in its normal condition admits of the entrance into it of solid particles of matter held in suspension in the fluid. But each of these experiments appears to be open to a different explanation. It is probable that the chemical action of the ink, by altering the condition of the envelope, allowed of the admission into it of solid particles only in proportion to the change in the tissue; and that the colour given to the envelope by frog's blood was due to particles of colouring matter which adhered to the surface, rather than to the admission of these into the substance of the tissue. This conclusion is founded on the following trials.

The imbibition of water by the covering of the egg being so distinctly marked, I had intended, like the authors mentioned, to endeavour to ascertain whether coloured water could be as readily absorbed as pure water. Through accident, however, I omitted to put this question to the test until late in the season of last year, and after the whole of my frogs had spawned. But having placed several ova in rectified spirit for future examination, at the moment of passing them from the body of a frog, I determined to test the result of the immersion of these in coloured fluid, although well aware of the correct objection that would be made, that the experiment must of necessity be inconclusive. I put some of these into a solution of carmine in water, and watched the result. The envelope, which, while the egg was in spirit, was white, opaque, and adhered closely around the yelk membrane, began to imbibe and expand the instant it was placed in the solution; and at the expiration of an hour there seemed reason to believe that the trial had succeeded. The envelope was much enlarged, and the fluid had penetrated into it, carrying with it some colouring matter; as on carefully washing the surface repeatedly in clean water, to remove the deposit on the exterior, the substance of the interior was seen to be coloured, and it was evident that the colouring matter had penetrated as far as the deepest or thick layer of the envelope. This result appeared to favour the view that the spermatozoon enters the ovum. When the ova were again examined at the end of the third day's immersion, they were of a deep red; the deepest stratum of colour being then between the vitelline membrane and the thick or innermost layer of the envelope. The entire egg presented the appearance of a globule or bead of red glass, with a dark red centre, surrounded by a lighter-coloured halo. The eggs were then thoroughly washed and placed in clean water. At the end of six hours part of the colouring matter had again been removed from the interior, and the eggs were of a less deep hue, and the water they had been immersed in was coloured. I then again removed them to clear water. At the end of sixteen hours they had parted with more colour, but were still red, more especially between the inner portion of the envelope and the vitelline membrane, and the water had again acquired a red hue, thus showing that both endosmose and exosmose must have taken place.

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* *Loc. cit.*, ii. p. 132.

As it might fairly be objected that these ova, changed by immersion in spirit, were unfitted for experiment, I made trial with others which had not been impregnated, and being infertile, had remained in water many days without giving signs of decay. When these were placed in the carmine solution, their envelopes became as deeply and thoroughly imbued with colouring matter throughout their whole substance as in the former; and when placed in clear water they parted as readily with a portion of it, so that it was evident that whenever the density of the fluid in which these dead and infertile ova were immersed, was altered, a change by endosmose or exosmose immediately took place in the fluid retained mechanically in their tissues. To this cause, perhaps, may be ascribed the colouring of the ova in Prevost and Dumas's first experiment with ink, while other experiments, which I shall mention, made on living and impregnated ova, lead me to regard the colour in the experiment with frog's blood as merely the result of adhesion of colouring matter to the surface.

The immediate objects I had now in view were, to learn whether impregnation is effected by any direct and palpable infiltration of seminal matter through the envelopes of the ovum;—whether the admixture of other matters with the seminal fluid will prevent or arrest impregnation;—and whether the spermatozoa collected on a filter paper, and then placed with this in a fluid of great density, are as efficient as in clear water.

With these views, I prepared a very dense solution of carmine pigment in water, and added parts of this to small quantities of water with ova, either before the seminal fluid was mixed with the water, or immediately afterwards, and I expected the results to show whether any solid particles, held in suspension in the fluid, passed through the envelopes. The previous trials had shown that solid particles do pass through the *dead* tissue, but it was doubtful whether the like result would occur in the living.

Carmine Experiments.—Set O. March 13, 1850. Atmosphere 53° Fahr.

No. 1. *Eleven unimpregnated ova* were passed into water mixed with carmine.

The envelopes became as fully expanded, and imbibed fluid as freely as in the impregnated ova, and acquired a red tint; but much of the colour was due to the deposition of granules of matter on the surface, while I was unable to detect any similar granules within their texture. On the contrary, on removing part of the surface of the envelopes, the interior, although slightly reddened, exhibited an uniform appearance.

No. 2. *Thirty ova* were passed into water that had been mixed with seminal fluid, and immediately *afterwards* a solution of carmine was also added.

Twenty-six of these ova became impregnated and produced embryos; thus showing that impregnation takes place very quickly, and is not prevented by the addition of a dense colouring fluid, added *after contact* with the impregnating fluid.

No. 3. *Forty-one ova* were passed into a solution of carmine in water which had been mixed with seminal fluid immediately *before* the passing of the ova.

Thirty-three of these ova also produced embryos. It was evident, therefore, that when seminal fluid is freely mixed with a dense medium that holds solid particles of matter in suspension, the spermatozoa are not necessarily prevented from effecting impregnation of the ova. Thus the ova of the Frog, although usually deposited in slow-running or clear still water, may be deposited even in slightly turbid water without impediment to the natural process of impregnation, as the water and spermatozoa may be brought into contact with the ova at the same instant.

No. 4. *Thirty ova* were passed into water mixed with fluid that had been almost completely deprived of spermatozoa by filtration.

Only *one ovum* exhibited any signs of impregnation, but not a single embryo was produced.

No. 5. About *two hundred and twelve ova* were passed into a dense solution of carmine and water in which the filter paper with spermatozoa, separated from the fluid employed in No. 4, had already been placed, and the water and ova were then freely agitated together.

The result of this experiment was very marked. Only a few of these ova became segmented, and the change proceeded much slower in them than in the ova of experiments Nos. 2 and 3. At the end of twelve days only *five embryos* had been produced. Thus a dense solution of carmine, applied to the spermatozoa *before* they are brought into contact with ova, may have the effect of preventing impregnation, apparently by operating as a mechanical impediment. These ova, excepting only a few removed for the following experiment, No. 6, which were taken from the mass as stated, were allowed to remain in the carmine for twenty-four hours before they were placed in clear water.

No. 6. *Forty ova* taken from the last experiment were removed to clear water at the end of one hour and a quarter, having first been thoroughly washed. The result was as decided as in No. 5. *Only two embryos* were formed; so that there was further reason to believe that impregnation takes place very quickly, and that the result in No. 5 was not entirely due to long continuance in the solution, but to some impediment at the time of contact.

No. 7. A thick solution of carmine was mixed with seminal fluid and water, and *three minutes afterwards* a mass of ova were passed into it.

This experiment was similar to No. 3, excepting only that the solution of carmine was much more dense, and the ova were not passed until three minutes after the fluids had been mixed. There was a marked difference in the result. Only a few of these eggs became segmented, and only *eight* out of a large mass produced embryos.

But there were several eggs that appeared to have been *partially impregnated*, the whole of which were abortive. *Partial impregnation*, as before stated, is shown in a very imperfect cleavage of the yelk, sometimes on one surface only, and sometimes complete as regards one half of the yelk, but imperfect or irregular in the other.

No. 8. *Forty-two ova* from the last experiment, No. 7, were removed from the carmine at the end of *thirty seconds*, and were immediately well washed to get rid of the adhering spermatozoa and granules of colouring matter. Not one of these ova produced an embryo, but several had become *partially impregnated.*

These experiments were made in the middle of March, when the season was unusually cold, and the mean lowest temperature of the room during twelve days was only 43° Fahr., and the mean highest 47° Fahr.; at a higher temperature the results, I have little doubt, would have been more favourable. The eggs had been impregnated however when the temperature, during the first twelve hours, was 55° Fahr., so that the question respecting the infiltration of solid matter with the water absorbed by the envelopes of the eggs was not affected.

About *four hundred and twenty* eggs were employed in this set of experiments; yet I could not detect any granules of the colouring matter of carmine held in suspension, and of dimensions equal to those of the spermatozoa, which had passed into the tissue of the envelopes of the eggs, although they had become tinged by the colouring matter in combination with the water. Abundance of granules of colouring matter of most minute size, and not more than one-third the diameter of the spermatozoa of the Frog seen beside them, adhered to the surface of the envelopes, and it was to these chiefly that the red colour of the whole was due. Every part of the envelope exhibited the same uniform appearance, the granules being pretty equally distributed over the surface, and the suffusion of colour was uniform in the interior. These facts appeared to be conclusive with reference to the question of the presumed existence of a fissure or perforation through the coverings of the egg of the Frog before, or at the moment of fecundation, as is supposed to exist in the ovum of the Rabbit. I have not been able to detect any appearance of orifice or fissure in the egg of the Frog-envelopes, and the course of which, if such really exists, would no doubt be indicated by some deposition of the colouring matter of the carmine, to a greater or less extent, in its tract. The result of these experiments was thus most unfavourable to the belief that the spermatozoa penetrate bodily through the membranes of the ovum; and to that of the supposed existence of a special opening in these membranes for their admission.

I ought now, however, to mention one experiment that seemed to favour the opinion that the spermatozoon enters the ovum. I had taken several ova, together with the oviducts into which they had passed, from the body of a *Lissotriton palmipes*, and others from that of *Triton palustris*, for the purpose of artificial impregnation. Some of these I pressed from the oviducts into a very clear solution of carmine, taken from a solution which had remained undisturbed for nearly a fortnight, so that the granules in suspension had subsided, and only the colouring matter actually combined with the water gave it its red hue. At the end of half an hour I removed the ova from the solution to clear water for examination, and then found that the interior of the envelope was coloured by the water which had entered, but that the greater portion of the colouring matter had been arrested and separated at its entrance and adhered to the surface. One ovum of *Lissotriton palmipes,* however, to my great surprise, had a little dense mass of colour deposited at one point only of the dark surface of the ovum, not merely within the envelope or its chamber, but actually beneath the vitelline membrane, between it and the yelk, as was distinctly proved by turning the egg on one side and viewing it in profile. Not one of the other eggs, placed in the solution, either of the *Triton* or *Lissotriton,* showed any appearance like this; so that while I am debarred from expressing a decided opinion that the spermatozoon does not enter the ovum, I can only regard the appearance mentioned as entirely accidental, and not as a normal occurrence; but as resulting, perhaps, from some minute puncture or other accident during the removal of the eggs from the body or the oviduct.

But in order, if possible, to remove another source of doubt, it seemed necessary to make some trial with the colouring material employed by Prevost and Dumas in their experiments; and some further examination of that used in my own; and to ascertain whether any solid particles or granules of matter, held in suspension in ink or in carmine, and equal in size to the spermatozoa of the Frog or the Newt, can be passed through the filter, or can be separated from the fluid portion by filtration, like the spermatozoa, when precisely the same mode is followed, and the same means and same description and number of filter-papers are employed, as in the filtration of the seminal fluid. The solution of these questions it was evident must tend to confirm or to unsettle the previous conclusions. I first tried *ink,* and used a part of the identical filtering-paper employed to separate the spermatozoa. The ink passed quickly and freely through three filters without losing any of its intense black colour, and carried with it only a very few extremely minute granules, much smaller in size than the spermatozoa of the Frog; so that it seemed fair to conclude that the colour imbibed by the ova from *ink,* in MM. Prevost and Dumas' experiment, was due to the admission of the chemically combined colours of the fluid, and not to an admission into the texture of the egg-envelopes of solid particles held merely in suspension in the fluid. Consequently this experiment seemed to negative the supposition that, from the fact of the interior of the egg-covering becoming blackened, solid particles of matter, equal in size to the spermatozoa, must have penetrated into the envelope during its expansion; and there seemed less reason to believe that the spermatozoa,—bodies very much larger than the ink-granules,—could enter it. *Carmine* was then tried. A solution of this colour could scarcely be made to pass through even a single filter. This seemed to be due chiefly to the fact that the greater proportion of the colouring matter of the carmine used (the water colour pigment of artists) was combined with gum and an earthy base, and consequently most of the colour was in suspension rather than in chemical combination. When placed on a single filter, the solution passed through with extreme difficulty and slowness. When a microscopic drop of the fluid so passed was examined with a power of three hundred diameters, it was found to contain a large quantity of granules suspended in clear fluid. When made to pass, but with still greater difficulty, through a second filter, it still contained a quantity of minute granules, but each *less than one-half the diameter* of the spermatozoon. It is *possible*, therefore, that some extremely minute granules may penetrate into the texture of the envelope, formed as it is of aggregations of cells; but it seems to be very improbable that any of the larger-sized objects, such as the spermatozoa, can enter: and it is even much more improbable, that if the chief colour of the ova in my experiments was due, as I believe, to granules of carmine on the surface, and not in the interior of the ova, that in MM. Prevost and Dumas' experiments with frog's blood, the ova should have become reddened by the admission of particles of this into their interior, since it need scarcely be mentioned that the colour of the blood is due only to the particles suspended in it; and MM. Prevost and Dumas remark, that they were not able to detect any blood-globules on the surface. To what else, then, than to these, or to their broken-down particles, could the reddened colour of the ova in their experiments be due?

The conclusion, then, to which I am led by these experiments is, that although the envelopes of the egg imbibe coloured fluid, they do so less easily than when the fluid is not coloured, unless it is in chemical combination; and although atoms of solid matter, very much smaller than the spermatozoa, may possibly be carried by infiltration into the texture of the egg-envelope by the act of endosmose during its expansion, it appears to be extremely unlikely that the large bodies of the spermatozoa are so carried in; an improbability which is raised almost to a certainty by the fact that the spermatozoa are not seen attached to the egg with a centripetal direction of the axis of their bodies, but are constantly applied laterally to, or are entangled amongst the loose tissue of the surface, extended at length or partially folded on themselves.

6. AGENCY OF SPERMATOZOA AS AFFECTED BY CHEMICAL MEDIA.

The experiments with carmine having led to an unexpected result in the impediment which this medium offers to the impregnation of the ovum when immersed in it before contact with the spermatozoa, I was desirous of ascertaining what effect would be produced on the ovum by the destruction of the spermatozoa by chemical means, immediately after they had been applied to it. Mr. Gulliver* long ago showed that the spermatozoa of different animals are variously affected by different chemical tests; and Dr. Frerichs†, more recently, has found that a solution of caustic potass has the property of entirely dissolving and destroying them. This material, therefore, seemed to be peculiarly fitted for the object in view. But before any experiment, in which this was employed, could be relied on, it was necessary to confirm the facts ascertained by chemical investigation, by observing the mode of action of solutions of caustic potass, and other chemical agents on the spermatozoa, by means of the microscope. As my observations on the effect of chemical agents on the spermatozoa have been confined for the present to those of the Frog, I shall state the results of these observations with the microscope before mentioning the experiments.

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* Proceedings of the Zoological Society, part 10. p. 101. July 26, 1842.

† In Cyclopædia of Anatomy and Physiology, Article "Semen," p. 506, January 1849.

All the observations were made immediately after the spermatozoa employed had been obtained, by the course already mentioned, and not by vivisection from the vesiculæ seminales or the testes, sources which are objectionable from the facts shown in Dr. Frerichs' analyses, that a large quantity of albumen is always found in the immature cells in the testes, with which the spermatozoa, obtained from that source, are constantly mixed, while there is no trace of albumen in the mature spermatozoa.

1. *Solution of Caustic Potass.*—The solution employed was in the proportion of twenty grains of caustic potass (*Potassa fusa*) to one ounce of water. This was the solution employed on most occasions in the following experiments, and which quickly and entirely dissolves the spermatozoa. When a drop of semen, in which the spermatozoa are active and abundant, covered by a pellicle of talc on a plate of glass, is attentively examined, while a very small quantity of the potass solution is applied to the edge of the talc, the act of dissolution is easily witnessed. As the solution spreads beneath the talc the spermatozoa first brought into contact with it are instantly destroyed, while the motions of those at a distance become slower and slower, until, when the fluid has nearly approached, they entirely cease. The instant the fluid comes into contact with the spermatozoa, they roll up on a sudden into a spiral form, the change commencing at the apex of the caudal extremity, and each becomes a rounded mass, which quickly dissolves and disappears in the homogeneous fluid. The action of the potass in this destruction of the spermatozoa, as seen by the microscope, is very similar to, in appearance, and strongly reminds one of the action of fire on the barbs of a feather, which become frizzled in an instant, leaving only a scoria that soon disappears.

2. *Nitrate of Potass.*—This, as in the preceding case, was in solution in the proportion of twenty grains to an ounce of water. It destroys the spermatozoa much less quickly than the caustic potass. When applied, as above, to the edge of the talc, the spermatozoa first become on a sudden motionless, and are in general elongated, and afterwards are very slowly dissolved.

3. *Diluted Acetic Acid.*—When this is applied to the spermatozoa in the same way as the solution of potass, it quickly destroys all signs of vitality. The movements immediately become slower and very soon entirely cease, and the spermatozoa are extended at full length, and are but rarely folded on themselves, as they usually are in natural death. I could not satisfy myself that the acid has any other effect on them chemically than that of contracting and rendering them smaller. It did not appear to dissolve them. Mr. Gulliver* has mentioned that the spermatozoa of the

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* *Loc. cit.*

snake (*Natrix torquata*) are not affected by acetic acid, but he makes no reference to its action on those of the Frog.

4. *Gum-Arabic.*—A thick solution of gum appears to act on the spermatozoa mechanically only, and almost immediately deprives them of motion by the obstruction it opposes to them. When a minute drop of spermatic fluid is placed in the midst of one of gum solution, and covered with talc, those spermatozoa which have become mixed with the gum cease to move instantly, and remain with the tail and body coiled in various directions; while others at the edges and in the midst of the fluid, where they are less mixed with gum, still move feebly for a few seconds, but become motionless as the gum collects around them.

These circumstances will better enable us to understand the following experiments, the object of which was to endeavour to learn how far the influence of the spermatozoa, and the *act* of impregnation of the ovum partake of a chemical or of a mechanical nature; and also will help to determine the length of period of contact requisite for impregnation.

The following experiments bear on these inquiries:—

Potass experiments.—*Set* P. March 25, 1850. Atmosphere 48° FAHR. Water 46° FAHR.

No. 1. P.M. 1^{h} 40^{m}.—*Fifty-four ova* were passed from the Frog on a dry surface, and were instantly bathed with recently-obtained impregnating fluid mixed with water; and at the lapse of *fifteen seconds* were washed by means of a hair-pencil loaded with the solution of caustic potass before mentioned; after which the eggs were again washed freely with water.

No. 2. P.M. 1^{h} 45^{m}.—*Thirty-nine ova* were treated in precisely the same way, except that the interval between the application of impregnating fluid and the solution of potass was only *five seconds*.

The ova were removed, after the first day, to a room in which the average temperature was about 60° FAHR., and at the end of the *eighth day twenty-one embryos*, advanced to near the end of the *fourth period* of development, had been produced in No. 1, and *two embryos*, at a similar stage, in No. 2. This, at first thought, appeared to be an extraordinary fact, seeing that the solution of potass so quickly decomposes the spermatozoa, and even renders the ovum sterile, as was afterwards found; but, on examination of the details, the experiments admit of explanation:—*first*, the seminal fluid was employed immediately it was obtained, and *before* the application of the potass, which was not used, in the first case, until after a lapse of *fifteen seconds*, and in the second case, of *five seconds*; next, that in both instances the solution of potass was, as quickly as possible after its application, diluted and removed by repeated washing of the ova with water. Nevertheless, these experiments prove that the ovum becomes impregnated very quickly after the application of spermatozoa, and, in these cases, even within the short interval of *fifteen seconds* in the one, and *five seconds* in the other, the difference in the number of embryos produced in the two apparently indicating the extent in each of the deleterious effect of the solution.

No. 3. P.M. 1^h 50^m.—*Forty-seven ova* were passed on a dry surface, and spermatic fluid was instantly applied to them, and within *ten seconds* afterwards the ova were washed with the solution of potass, which was allowed to remain, and water was then added. At the end of the *eighth day* not a single embryo had been produced. The difference between this experiment and the above was the non-removal of the potass, and the more free bathing of the ova.

No. 4. P.M. 1^h 53^m.—*Forty-five ova* were passed on a dry surface, and were *first* bathed with solution of potass, and then with seminal fluid in water, and afterwards they were removed with No. 1 and 2, to higher temperature.

At the expiration of the *eighth* day *three embryos* had been formed. This result at first appeared to be more difficult of explanation than the former. But, when the circumstances are considered, it seems to admit of quite as easy an interpretation. The bathing of the ova freely with seminal fluid mixed with water, *five seconds after* the application of the solution of potass, diluted this solution too much to allow of its effect on the whole of the spermatozoa applied to the ova, while this very dilution enabled the impregnating influence of these bodies to take effect in some of the ova. The fact, however, leads to an inference of some importance with reference to the action of the potass on the envelopes of the ovum, and seems to show that this action is less immediate on the envelopes than on the spermatozoa.

No. 5. *Fifty-nine ova* were bathed with seminal fluid and water, and *five seconds afterwards* with a solution of nitrate of potass (in the proportion of twenty grains of the salt to one ounce of water), and water was then added to them.

No. 6. *Seventy-two ova* were treated in precisely the same way.

Not one embryo was produced in either of these experiments.

No. 7. *Forty-four ova* were washed with diluted *acetic acid* immediately after they had been shed from the female, and *five seconds afterwards,* seminal fluid with water was added to them.

No. 8. *Seventy-six ova* were washed with diluted acid, and treated in every way as in No. 7.

Not a single embryo was produced in either of these trials.

The action of acetic acid is almost instantaneous on the envelope of the ovum, which it quickly contracts, and renders slightly opaque.

Besides those media which act *chemically* on the spermatozoa and the ova, I made trial, in this and the two following sets of experiments, with a solution of gum-arabic, the effect of which appears to be entirely *mechanical*; and as the results are curious and seemingly important with reference to the nature of the agency of the spermatozoa in impregnation, I defer the mentioning of them until I have to show the effect of media which operate mechanically on the ovum or the spermatozoon in impregnation.

The result of the preceding experiments was so remarkable, that it seemed necessary that they should be repeated with greater precision, with reference to exact periods of time, than can always be done when alone and unassisted. It was evident that a proper understanding of the nature of the act of impregnation, if ever this becomes known, will be led to chiefly by attention to the *periods of time* in which it is effected. I obtained therefore the assistance of a friend, to note the spaces of time which elapsed in each stage of the following experiments, so that these might be performed with the quickest dispatch, and the attention of the experimenter be not withdrawn from each until it was completed.

Set Q. March 30, 1850. Atmosphere 49° FAHR.

The seminal fluid employed in this set of experiments was not obtained from the usual source. From some cause or other it could not be so procured. I therefore killed a male frog, by dividing the spinal cord in the *medulla oblongata,* and pressed out the fluid from the testes, which were gorged with spermatozoa, as found by examination with the microscope. From the presence of a great number of spermatozoal cells, and from the water with which I mixed the fluid becoming slightly turbid and albuminous, it was seen that it was not fully matured, a circumstance to be borne in mind with reference to the experiments, which were commenced some minutes after the fluid had been thus obtained. It was doubtful also whether the eggs were quite mature.

It is necessary further to mention, that in these experiments two solutions of potass, with different proportions of the salt, were employed; one having twenty grains in one ounce of water, and which, to avoid repetitions, I shall designate "*strong solution*;" and the other having only eight grains of the salt in one ounce of the fluid, and which I shall refer to as the "*weak solution*."

No. 1. P.M. 4^h 45^m.—*Forty-five ova,* passed on a dry surface, were bathed with seminal fluid and water, and *five seconds afterwards* with the *weak solution* of potass, and were then washed, and placed in clean water. The whole time occupied in the experiment did not exceed *thirty-five seconds.*

On the following morning, segmentation was found to have taken place in *twelve ova.* This as well as the following sets of ova were then removed to a higher temperature, in which they were allowed to remain; but *no embryos* were produced.

No. 2. P.M. 4^h 58^m.—*Fifty-three ova* were treated in exactly the same way, but with the *strong solution* of potass; the *interval* between the application of the impregnating fluid and the solution being only *two seconds,* and the whole time occupied *forty-five seconds.*

Segmentation took place in *three or four ova,* but not completely. Several ova also were altered in form; but *not a single embryo* was produced.

No. 3. P.M. 4^h 52^m.—*One hundred and twenty-two ova,* passed on a dry surface, were immediately well bathed with seminal fluid and water, and *two seconds afterwards* with *weak solution* of potass, which was *allowed to remain with the ova,* and water was then added. The whole time occupied was *forty-five seconds.*

Segmentation took place in a great number of these ova, certainly from *fifty to* *sixty,* and there were nine also which became shrivelled and decayed. Notwithstanding the great proportion of ova segmented, *not one produced an embryo.*

No. 4. P.M. 5^h.—*Sixty-six ova,* passed on a dry surface, were bathed as in No. 2, with impregnating fluid, and *one second afterwards* were washed quickly with *strong solution* of potass, and water was then added; the period occupied being *sixty-two seconds.*

Only *two ova* became segmented, while, excepting only eight or nine ova, the whole of the remainder were shrivelled, irregular, or compressed in form, and distinctly spoiled, apparently by the action of the potass, thus showing that endosmose and exosmose through the envelopes had taken place.

No. 5. P.M. 4^h 55^m.—*Fifty-four ova* were passed, and washed with the *weak solution* of potass, and *afterwards,* at an interval of *two seconds,* with impregnating fluid and water, and water was then added and allowed to remain. The whole time occupied was *fifty seconds.*

One ovum only became segmented; but several others had slightly altered their form to the obtuse oval, as if about to become divided: *no embryo* was produced.

No. 6. P.M. 5^h 2^m.—*Seventy-nine ova* were washed with *strong solution* of potass, and one *second* afterwards with impregnating fluid, and water was then added.

Not one ovum became segmented, nor did even one yelk retain its proper shape. The whole were irregular and spoiled. *Five ova* had the envelope clouded and opaque, and the surface of others was translucent with refracted light, like crystallized carbonate of lime. In one egg only had there been any attempt at segmentation. This experiment, like No. 4, seemed to show that the act of expansion of the chorion is an act of endosmose.

No. 7. P.M. 5^h 15^m.—*Nitrate of Potass. Seventy-seven ova* were passed on a dry surface, and were well bathed with impregnating fluid in water, and *one second* afterwards with a *weak* solution of nitrate of potass, and water was then added to them; the whole time occupied being *thirty seconds.*

Segmentation took place in *forty-three* of these ova, and the whole retained their natural form and size. The effect of the nitrate of potass, as compared with the caustic solution, was thus very marked, as showing that the momentary application of the nitrate does not prevent or arrest impregnation in weak solution (eight grains to one ounce of water), even when applied *after* the impregnating influence. The experiment was also interesting in another respect. It proved that the ova were susceptible of being impregnated, and that the fluid from the testes was efficient to induce the first evidences of impregnation. But none of these ova, or of the ova in the preceding experiments of this set, produced embryos. Subsequent observations will show that this failure was not due to the nitrate of potass, but perhaps was attributable to the conjoint causes of low temperature at the time of impregnation, and of some imperfection both in the seminal fluid and the ova.

No. 8. P.M. 5^h 9^m.—*Seventy-six ova* were washed with diluted *acetic acid* as in *Set* P, No. 7, and *one second* afterwards with impregnating fluid, and water was then added to them. The time occupied was *forty-five seconds.*

The result was more decided than in the experiment referred to. The envelopes of the ova immediately became clouded, and no segmentation took place in any of the yelks, some of which became shrivelled and changed in form.

The result of the preceding experiments being doubtful as to the cause of the non-production of embryos, especially with reference to the first three, and the seventh experiments, in which many ova became segmented, I obtained some additional pairs of frogs from their native haunts, and within twenty-four hours afterwards, before they had in any way become debilitated by confinement, repeated the experiments at a higher temperature.

Set R. April 3, 1850. Atmosphere 60° FAHR.

No. 1. P.M. $3^h\ 5^m$.—*Eighty-two ova*, passed on a dry surface, were touched for *an instant only* with a pencil dipped in impregnating fluid and water, and *one second afterwards* were washed with *strong* solution of potass, and then with water, and water was then added. The whole time occupied was only *fifteen seconds.*

No. 2. *Twenty-five ova* were treated in precisely the same way with the same solution (which also was employed in the following experiments); the interval being *two seconds*, and the whole time *twenty seconds.*

Segmentation took place, but *only very partially*, in about *twelve ova* of the first, but completely in *one only* of the second experiment. The whole of the remaining ova were shrivelled and decayed; their envelopes exhibiting the same clouded and refractive property noticed in the last set. At the end of five days *two embryos* had been produced in the first experiment, and *one* in the second. It was thus far confirmatory of the experiments with potass in *Set* P, that if this salt be applied to the envelope *several seconds after* the application of the impregnating fluid, and be again *quickly removed or diluted* with water, impregnation may already have taken place, and the action of the caustic will not in that case affect the production of the embryo; especially if the experiment be made when the temperature of the surrounding medium is becoming increased. But if the solution be applied *before* the application of the seminal fluid, then the spermatozoa will in most cases be decomposed, and no impregnation follow. In either case, however, the undiluted solution acts also on the ovum itself within a very short period, and destroys or renders it sterile. This was further proved in the succeeding experiments.

No. 3. P.M. $3^h\ 10^m$.—*Fifty-eight ova* were passed on *a moistened surface*, and were immediately afterwards washed with the solution, and at the expiration of *one second* were bathed with seminal fluid and water; the time occupied being only *fifteen seconds*, as in No. 1.

No. 4. *Sixty-nine ova* were treated in exactly the same way, the interval being *one second*; and the whole time occupied only *twelve.*

Partial segmentation had taken place in *one ovum* of No. 3; but the whole of the remaining ova, both in No. 3 and 4, were destroyed. Many of the yelks had begun to change form within the first hour, and the envelopes exhibited the same refractive appearance as in the previous experiments.

Anticipating from the former experiments what probably might be the ultimate result in these, I now determined to put beyond the possibility of doubt, both the fitness of the seminal fluid employed to effect impregnation and the healthiness of the ova, and their susceptibility to become impregnated; and to show from these facts that a non-production of the embryo *in this set of experiments* must be due to the action of the potass solution, and not to any unfitness in the spermatozoa or the ova. Accordingly,—

No. 5. P.M. 3h 17m.—*Sixty-two ova,* from the same female employed in the preceding experiments, were bathed with a portion of the seminal fluid and water which had been employed in No. 1 and 2, and were then placed side by side with these, in a separate dish.

At the expiration of *four hours and thirteen minutes,* the temperature being 60° FAHR., from *thirty to forty* of these ova had become segmented. Some of the ova had been injured mechanically, but nearly the whole that had not been injured were impregnated. On the *seventh day* there were *twenty-three embryos, thirteen* of which had already left the egg-envelopes; others were somewhat less advanced, thus proving the fitness of the seminal fluid to impregnate, and the ova to produce. The number of embryos too was fully as great as could have been expected, seeing that many of the ova had been slightly injured, and that the seminal fluid had already been *one hour and twenty-six minutes* mixed with water.

The result of this experiment was borne out by the following.

No. 6. P.M. 3h 31m.—*Nitrate of Potass. Seventy-four ova* were well bathed with impregnating fluid and water on a previously dry surface, and *one second* afterwards with a *strong solution* of nitrate of potass (twenty grains to one ounce of water), and water was then added to them; the whole time of the experiment being *twenty seconds.*

No. 7. *Fifty-nine ova* were treated in exactly the same way, save that the interval between the application of the impregnating fluid and the solution of potass was *three seconds,* and the whole period *twenty-five seconds.*

Segmentation commenced in each of these sets in *four hours and fourteen minutes,* when from *twelve* to *fifteen* ova were undergoing this change in No. 6, and *thirteen* in No. 7. At a later hour there were many more in each experiment only very partially segmented, and which proved to be unproductive. At the end of the *seventh day* there were *twelve embryos* in No. 6 advanced to the same stage as in the *simply artificial impregnation* No. 5, and *ten embryos* in No. 7, but at a little less early stage of growth, a circumstance which I attributed at the time to imperfect aëration.

No. 8. P.M. 3h 37m.—*Seventy-nine ova* were bathed with the same solution of nitrate of potass as above, and *three seconds afterwards* with impregnating fluid in water; the whole time occupied being *twenty seconds.*

Segmentation took place at a little later period in this than in the preceding experiments. It commenced at *four hours and twenty minutes*, when *twenty-five ova* were undergoing the change. This was a full proportion of impregnation as compared with No. 5, seeing that the impregnating fluid had already been mixed with water one hour and forty-six minutes. *Twenty-five embryos* were the result of this experiment.

The results thus support the explanation already given, with reference to the effect produced on the envelopes of the ovum being less immediate than on the spermatozoa; since, in this case, twice as many ova became segmented, and ultimately produced embryos, as in those experiments in which *the solution* was applied *after* the seminal fluid, and while endosmosis of the egg was most rapid, and when the solution remained undiluted.

The general results of this set of experiments, compared with those of the last *Set*, Q, appear also to show that the non-production of embryos in the whole of that set,—after segmentation had taken place in several of the experiments, as in Nos. 1, 2, and especially No. 3, with solutions of the caustic potass;—and still further, No. 7 with the *nitrate*,—may fairly be attributed to some defect in the seminal fluid or in the ova; since, if such were not the cause, and the failure had been due either to the chemical effect of the media on the ova, or to the moderate temperature of the atmosphere (49° Fahr.) at the time of experiment,—segmentation of the yelk would hardly have taken place. This supposition appears to be the more likely, when we recollect that in the *Set* Q, and *in that set only*, the impregnating fluid was obtained from the testes, compressed and broken down in water,—that the eggs were of doubtful maturity,—and that this was *the only set of experiments in which no embryos were ultimately produced*; although, I may now mention, that greater care was taken to ensure a favourable result than in most of these investigations,—the ova being removed at the end of twenty hours to an average temperature of 60° Fahr.,—were retained in flat shallow dishes,—and had the water changed daily. Both sets, however, Q and R, seem to prove that the *act* of impregnation, as evidenced in the fact of the yelk becoming segmented, must take place, or be commenced very rapidly; and, apparently, *almost at the instant of contact of the spermatozoon with the coverings of the ovum*; as seems to be shown in the fact, that segmentation took place in many of the ova when the space of time between the application of the spermatozoon, and that of the solution,—which previous observation (p. 225) showed was sufficient to decompose it immediately,—was scarcely more than *one* or *two seconds*. Thus in Q 4, and R 1, it must have commenced in the interval of *one second*, even when the strong solution was used; and in Q 2 and R 2 with the same solution in *two seconds*. When the weaker solution was used, a greater number of ova became affected in similar spaces of time, as in Q 2 and 3. These experiments seem to show that the *act* of impregnation had already been *commenced* before the application of the solution; as, in the experiments which are the converse of those now mentioned, in regard to the time when the spermatozoa and the solution were applied, a different result ensued. Thus when the *solution* was applied to the ovum *first* as in Q 6 and R 3 and 4, and *one* *second afterwards* the impregnating fluid with spermatozoa, no impregnation, or but a very partial one, was effected. The ova in these three experiments amounted to *two hundred and six,* and yet only *one ovum* became very partially affected. A like result ensued even when the weaker solution was employed at an interval of *two seconds,* as in Q 5, when out of *fifty-four ova* segmentation occurred but in *one.*

When the interval between the application of the impregnating fluid, in the first instance, and that of the solution subsequently, was extended to *five seconds,* then a greater proportion of ova became segmented, as in Q 1, with the weak solution, when out of *forty-five* ova *twelve* became changed.

These were the results when the experiments were made at different temperatures, as at 49° Fahr. with the *Set* Q, and 60° Fahr. with the *Set* R. They cannot, therefore, be attributable to inertness of the fecundating agent, or of the object to be fecundated, occasioned by an unfavourable temperature of the surrounding medium. The fact of the occurrence of segmentation in some ova, but not in the majority of the ova of different experiments, as in Q 1, 2, 3 and 4, seems further to show that the influence of the momentary application of the potash solution was produced chiefly, and in the first instance, on the spermatozoa, or impregnating bodies, and not so immediately on the ova; since if the ova had been first, or most affected, none of them, probably, would have become impregnated.

Further, I may perhaps be allowed to remark, that the arrest of impregnation was due mainly to the nature of the chemical agent employed; and the extent of interference with the fecundatory process was in proportion to the more or less immediate action of this agent on the spermatozoon. Thus we have seen that but few ova were impregnated when the solutions of caustic potass were employed; but when the nitrate of potass was used as in Q 7, *forty-three* out of *seventy-seven ova* were segmented; while in R 6, 7 and 8, in which the total number of ova was *two hundred and twelve,* there were *fifty-three* segmented, and these produced *forty-seven embryos.*

The object of these sets of experiments, therefore,—that of endeavouring to ascertain within what period of time after the contact of the spermatozoon with the ovum its fecundatory function is exerted,—appears to have been somewhat fulfilled;—in so far as that in these experiments on the *Amphibia* the *commencement of the act of impregnation appears to have been almost instantaneous.* Yet there seems reason to believe that momentary contact of the impregnating body, even in the ovum of these animals, is not in itself sufficient to complete the fecundation, although it may tend to induce that condition of the yelk, segmentation, which we now are assured is always indicatory of its having been influenced by the fecundatory agent. If momentary contact were sufficient for the completion of the function, then partial impregnation, which so frequently takes place when spermatozoa are few in number, or in contact only for very brief periods, could hardly happen; while every ovum in which the process of cleavage is begun ought to pass through all its changes to the production of the embryo, circumstances being favourable to its development. But this we have seen in the foregoing experiments is not the case. On the contrary, *duration* of at least some *seconds* of contact, varying no doubt in different tribes of animals, and, apparently also, *quantity* of spermatozoa, seem to be essential to fruitful and healthy impregnation, as appears to be shown in the *filtration experiments, Set* L 3, as compared with L 1 (p. 207). Possibly momentary contact may suffice to occasion segmentation, but certainly with *duration* of contact the ovum is fecundated.

This leads us further to inquire whether any endosmosis of the material substance of the spermatozoon is imbibed by the ovum during any period of impregnation, before or during segmentation of the yelk?—and whether those media which do not act chemically on the spermatozoon or the ovum can arrest the agency of the former? Bischoff has already shown that spermatozoa are in contact with the ovum in some Mammalia, the Rabbit* and Dog†, from quickly after the entrance of the ovum into the Fallopian tube until segmentation is nearly completed, and the yelk has acquired a tuberculated or mulberry-like surface. In the ovum of the Frog I have shown that the spermatozoa are in like manner seen on the envelopes from immediately after immersion in impregnating fluid until segmentation has commenced. In the Newt we have seen that *when impregnation is effected artificially*, they may be recognized on the surface for a much longer period,—from the time of contact with fluid, until the surface of the yelk has reacquired its original smoothness, a period, in my observations, of from thirty-six to forty-eight hours. The persistence of these bodies to a period after the first evident changes in the yelk have commenced, seems to favour a supposition that their function is not completed in momentary contact. Although we are at present unable to trace their influence beyond what is now stated, I think it can be shown that their function can be arrested by media which affect them mechanically, when submitted to such media at the moment of contact with the ovum.

7. AGENCY OF THE SPERMATOZOA AS AFFECTED BY MECHANICAL MEDIA.

The object of the next experiments was to learn whether the interposition of a dense fluid medium, which does not act chemically on the spermatozoa, would be as effectual in preventing the influence of these bodies on the ovum as in the *carmine experiments*, the effect of which seemed to be mechanical.

As the experiments were made at different periods, it will be seen, that although on two of these occasions the temperature of the atmosphere differed, the general results were similar.

Gum and Starch Experiments.—Set S. March 25, 1850. Atmosphere 48°.

(*a*.) *Gum.* No. 1. P.M. 2^h 22^m.—*Seventy-six ova* were passed on a *dry surface* and were immediately bathed with a thick solution of gum-arabic, and *fifteen seconds afterwards* with seminal fluid and water, and fresh water was then added to them. The whole time of the experiment was *sixty seconds.*

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* Entwickelungsgeschichte des Kaninchen-eies. 4to. 1842, tab. 2, 3 and 4, fig. 17 to 28.

† Entwickelungsgeschichte des Hunde-eies. 4to. 1845, tab. 1 and 2, figs. 10 to 16.

No. 2. *Fifty-eight ova* were treated in exactly the same way, the interval being about *fifteen seconds*, and the whole time *sixty*.

The seminal fluid employed was obtained from two males, the fluid used to No. 2 being from a male which had paired four days before. Out of the whole number of eggs in the two sets, amounting to one hundred and thirty-four, not one produced an embryo.

No. 3. March 30, 1850. P.M. $5^h\ 5^m$. Atmosphere 49° Fahr.

One hundred and eight ova were passed on a *moist* surface, and were immediately bathed with a thick solution of gum as above, and one *second afterwards* with seminal fluid in water; the whole time occupied being *sixty seconds.*

Segmentation took place in *two*, or at most only *three* of these ova, and even in them very imperfectly, and much slower than in the corresponding ova of the set to which they belonged, *Set* Q (p. 228–9), in which the fluid employed was obtained from the testes of the Frog, and regarded as immature.

No. 4. P.M. $5^h\ 18^m$.—*Fifty-eight ova* passed on a *moistened* surface were immediately bathed with solution of gum, and one *second afterwards* with seminal fluid from the same male as No. 3. The whole time occupied was *forty-five seconds.*

The result of these two experiments, as compared with others of the set to which they belonged, *Set* Q, was exceedingly curious. In the experiments with the nitrate of potass as in Q 7, segmentation was carried to some extent, and the divisions of the yelk were multiplied; while only *four ova* out of the fifty-eight, in this with gum, gave any evidence of segmentation, and the process was not advanced further, either in this or in the preceding experiment, No. 3, than to the completion of the primary division of the yelk into two hemispheres. Thus not only was the process entirely prevented in the great majority of the ova, but it was also very much retarded in those in which it did take place, and this simply, as it appeared, by the mechanical hindrance of the gum. Could it be that the effect was produced on the endosmic action of the yelk? These trials certainly appeared to show that the obstruction was a mechanical one. I need scarcely remark, that *no embryo* was produced in either of these experiments.

No. 5. April 3, 1850. P.M. $3^h\ 25^m$. Atmosphere 60° Fahr.

Sixty-one ova were passed on a *moistened* surface and were immediately bathed *with impregnating fluid,* and *two seconds afterwards* with a thick solution of gum-arabic, and water was then added; the whole time occupied being only *twenty seconds.*

This experiment, when compared either with the four preceding ones, made at a temperature of the atmosphere eleven degrees lower, or with that which follows, No. 6, seems to point to the exact nature of the operation of the gum. At *four hours* and *five minutes* from *fifteen* to *twenty* ova had become segmented, and others were in the act of becoming so. At *seven hours and a half* more than one-half of the whole number had changed, and were perfectly healthy. Thus, in this case, in which the gum was applied *after* the seminal fluid, impregnation occurred *earlier* than in corresponding experiments of the same set, R 6, 7 and 8, with nitrate of potass, when it happened in from *four hours,* and *fourteen* to *twenty minutes.* It was even as rapid as in the artificial impregnation, R 5 (p. 231), in which it took place in *four hours and thirteen minutes.* On the eighth day *twelve embryos* had been produced.

These facts seemed to show, precisely as in experiments with solutions of potass, that impregnation is commenced very quickly; and further, that it was not arrested by the gum when applied only *two seconds* after the spermatozoa, but that the change proceeds almost as uninterruptedly as in a perfectly natural impregnation, since the number of embryos was almost as great as in No. 5 R, seeing that the fluid employed had been obtained and mixed with water one hour and thirty-four minutes.

No. 6. P.M. 3h 22m.—*Seventy ova,* passed on a moistened surface, were bathed with a thick solution of gum, and *two seconds afterwards* with some of the impregnating fluid employed in the last experiment, and water was then added; the whole time occupied, as above, being only *twenty seconds.*

This experiment was the converse of the preceding. At *four hours and twenty-eight minutes* only one egg out of the whole had become segmented; but others gave signs of being about to change, and some hours later a few had done so, but there were not at most more than *ten.* At the end of the *seventh* day *two embryos* had been produced.

Thus while a comparison of these two experiments seems to show that the gum acts simply as a mechanical obstruction to the process of fecundation, this experiment, No. 6, when compared with Nos. 1 to 4, made at eleven degrees lower temperature, shows also the influence of a higher degree of temperature in accelerating fecundation.

The two following experiments were made with a view to test the efficiency of the fluid and ova employed, now at one hour and fifty minutes after the fluid had been obtained: when examined at this time with the microscope, there were still an abundance of active spermatozoa.

No. 7. P.M. 3h 41m.—*Eighty-five ova* were accordingly placed in water with some of the impregnating fluid and allowed to remain to test its efficacy.

At *four hours and twenty-four minutes* nearly the whole of the ova had become segmented, and on the seventh day *forty-two embryos* had been produced.

No. 8. P.M. 5h 50m.—*One hundred and thirty-two ova* were now passed into the remainder of the impregnating fluid, which had at this time been *four hours* mixed with water.

When examined at the end of five hours and ten minutes, not a single specimen had become impregnated. This was proved by the result, that at the end of seven days *not a single embryo* had been formed. The fluid had thus lost its fecundating property at the end of four hours in a temperature of 60° FAHR.

No. 9. April 6, 1850. Atmosphere 60° FAHR.

P.M. 1h 50m.—One more experiment was now made with the gum solution, for the purpose of comparing it with the following experiments with starch.

One hundred and twenty-two ova were passed on a dry surface and covered with a thick solution of gum, and *three seconds afterwards* with impregnating fluid that had been mixed with water only *thirty minutes.* The time occupied was not noted, but fresh water was added to the ova at the end of fourteen minutes.

Segmentation took place only, in two or three ova, at *four hours and twenty-four minutes,* and at the end of ten days only *three embryos* had been produced.

(*b.*) *Starch.* No. 10. P.M. $1^h\ 40^m$.—*One hundred and fifty-eight ova* were passed into a solution of starch in water, and at the end of *ten seconds* one-half of the whole quantity of seminal fluid, obtained from a single frog, and previously mixed with water, was added to them.

After the ova had remained in the solution and been gently agitated during twenty minutes, they were carefully washed and removed to clear water.

At *four hours and twenty-six minutes* only a very few of these ova, not more than eight or ten, had become segmented, notwithstanding the large quantity of recent impregnating fluid that had been added to them. At the end of ten days only *five embryos* had been produced.

It was remarkable that very few of the ova in this experiment cohered together, as the frog's ova almost invariably do when placed in fluid. On the contrary, most of them remained separate and isolated, although their envelopes had imbibed water and expanded to their usual extent in a similar space of time.

No. 11. P.M. $1^h\ 47^m$.—*Seventy-one ova* were passed on a perfectly dry surface, and immediately afterwards were covered, by means of a hair-pencil, with a thick solution of starch, and at the expiration of *ten seconds* with impregnating fluid, and water was quickly added.

The water was changed at the end of fifteen minutes. At *four hours and twenty-five minutes,* only two or three ova had become segmented. At the end of ten days *three embryos* had been produced.

The concluding experiment with starch was the counterpart of No. 5, with *gum.*

No. 12. P.M. $1^h\ 44^m$.—*One hundred and nineteen ova* were passed into water, with which one-eighth part only of the seminal fluid, obtained from the Frog, had already been mixed. *Two seconds* afterwards a solution of starch was added to these ova, and at the end of sixteen minutes they were removed to clear water.

In *four hours and twenty-six minutes* segmentation had commenced in many of these ova. The exact number I omitted to ascertain. But the change had taken place in a much shorter space of time, and was more general, although scarcely one-fourth part of the quantity of seminal fluid that had been employed in No. 10 was used in this case. Nevertheless, in ten days *twelve embryos* had been formed.

This experiment, therefore, was quite confirmatory of the conclusions drawn from its counterpart, No. 5, with *gum,* and Nos. 10 and 11 as fully bore out those deduced from Nos. 1 to 5, with the same; while the entire set seem to be in full accordance with the already arrived at conclusion, that fecundation is commenced almost immediately the fecundating body is in contact with the ovum. Thus, then, with regard to the nature of impregnation, we seem to have obtained sufficient proof that the *act* is effected through the agency of the spermatozoon, and not through that of the *liquor seminis,* as was formerly supposed.

Table II.—Experiments with Media that act *chemically* or *me-*

No. of experiments.	Date and hour of experiment.	Temperature at the time of the experiment.		Mean daily temperature after the experiment.	Segmentation commenced in hours.	No. of eggs		Embryos at		Nature of the impregnating fluid.	Time, procured and mixed with water.
		Atmosphere.	Water.			Employed.	Segmented.	End of third stage.	In days and hours.		
1850.											
Set P. 1.	March 25. P.M. 1 40	48	46	61	......	54	......	20	4^{d} 12^{h}	Semen and water.	10^{m}
2.	P.M. 1 45	48	46	61	......	39	......	2	4^{d} 12^{h}	Semen and water.	15^{m}
3.	P.M. 1 50	48	46	61	......	47	......	Not one.	Not one.	Semen and water.	20^{m}
4.	P.M. 1 53	48	46	61	......	45	......	3	5^{d}	Semen and water.	23^{m}
5.	P.M. 2 21	48	46	61	......	59	......	Not one.	......	Semen and water.	51^{m}
6.	P.M. 2 26	48	46	61	......	72	......	Not one.	......	Semen and water.	56^{m}
7.	P.M. 2 16	48	46	61	......	44	......	Not one.	......	Semen and water.	46^{m}
8.	P.M.	48	46	61	......	76	......	Not one.	......	Semen and water.	10^{m}
Set S. 1.	P.M. 2 22	48	46	61	......	76	......	Not one.	......	Semen and water.	52^{m}
2.	P.M.	48	46	61	......	58	......	Not one.	......	Semen add water.	12^{m}
Set Q. 1.	30. P.M. 4 45	49	48	61·5	......	45	12	Not one.	......	Semen from testes.	10^{m}
2.	P.M. 4 58	49	48	61·5	......	53	4	Not one.	......	Semen from testes.	23^{m}
3.	P.M. 4 52	49	48	61·5	......	122	50 to 60	Not one.	......	Semen from testes.	17^{m}
4.	P.M. 5	49	48	61·5	......	66	2	Not one.	......	Semen from testes.	25^{m}
5.	P.M. 4 55	49	48	61·5	......	54	1	Not one.	......	Semen from testes.	20^{m}
6.	P.M. 5 2	49	48	61·5	......	79	......	Not one.	......	Semen from testes.	27^{m}
7.	P.M. 5 15	49	48	61·5	......	77	43	Not one.	......	Semen from testes.	40^{m}
8.	P.M. 5 9	49	48	61·5	......	76	......	Not one.	......	Semen from testes.	34^{m}
Set S. 3.	P.M. 5 5	49	48	...	18 to 20^{h} at temp. 49 to 48°	108	3	Not one.	......	Semen from testes.	30^{m}
4.	P.M. 5 18	49	48	...	18 to 20^{h}	58	4	Not one.	......	Semen from testes.	43^{m}
Set R. 1.	April 3. P.M. 3 5	60	...	...	4^{h}	82	12 partial	2	6 to 7^{d}	Semen and water.	1^{h} 12^{m}
2.	....	60	...	...	......	25	1	1	6 to 7^{d}	Semen and water.	......
3.	P.M. 3 10	60	...	...	$4\tfrac{1}{4}^{h}$	58	1 partially	Not one.	......	Semen and water.	1^{h} 17^{m}
4.	....	60	...	...	......	69	......	Not one.	......	Semen and water.	1^{h}
5.	P.M. 3 17	60	...	...	4^{h} 13^{m}	62	30 to 40	23	5^{d}	Semen and water.	1^{h} 24^{m}
6.	P.M. 3 31	60	...	...	4^{h} 14^{m}	74	12 to 15	12	5^{d}	Semen and water.	1^{h} 38^{m}
7.	....	60	...	...	4^{h} 14^{m}	59	13	10	5^{d}	Semen and water.	......
8.	P.M. 3 37	60	...	...	4^{h} 20^{m}	79	25	25	5^{d}	Semen and water.	1^{h} 46^{m}
Set S. 5.	P.M. 3 25	60	...	...	4^{h} 5^{m}	61	33	11	5^{d}	Semen and water.	1^{h} 34^{m}
6.	P.M. 3 22	60	...	...	4^{h} 30^{m}	70	10	2	7^{d}	Semen and water.	1^{h} 31^{m}
7.	P.M. 3 41	60	...	...	4^{h} 24^{m}	85	74	42	6^{d}	Semen and water.	1^{h} 50^{m}
8.	P.M. 5 50	60	...	...	......	132	Not one.	......	......	....	4 *hours*
Set S. 9.	6. PM. 1 50	60	...	...	4^{h} 24^{m}	122	3	3	7^{d}	Semen and water.	30^{m}
10.	P.M. 1 40	60	...	...	4^{h} 20^{m}	158	8 or 10	5	7^{d}	Semen and water.	20^{m}
11.	P.M. 1 47	60	...	...	4^{h} 25^{m}	71	3	3	7^{d}	Semen and water.	27^{m}
12.	P.M. 1 44	60	...	...	4^{h} 18^{m}	119	......	12	$5\tfrac{1}{2}^{d}$	Semen and water.	24^{m}
					Total number	2634	369	176	in Sets P, Q, R, & S.		

RECAPITULATION AND CONCLUSIONS.

It may now be well to recapitulate briefly some of the facts and views derived from the foregoing observations and experiments. *First*, then, the *germinal vesicle* disappears in the Amphibia before impregnation; and before, or at the time of the bursting of the ovisac, and extrusion of the egg from the ovary into the cavity of the *chanically* on the Spermatozoon or the Ovum in Impregnation.

Material employed.			Period of experiment.			Remarks.
Operating mechanically.	Operating chemically.	Quantity per ounce of water.	Interval *before* fluid.	Interval *after* fluid.	Whole period.	
....	*Solut. caust. pot.*	℈j to ℥j.	......	15 sec.	1^m	No. 1 to 8 of this set removed after fifty minutes to temperature 61° Fahr. These ova were passed on a dry surface, and fluid applied freely with a pencil, and afterwards the potass washed off freely with water.
....	Solut. caust. pot.	℈j to ℥j.	......	5 sec.	40 sec.	
....	Solut. caust. pot.	℈j to ℥j.	......	10 sec.	30 sec.	Potass allowed to remain.
....	Solut. caust. pot.	℈j to ℥j.	5 sec.	......	30 sec.	Ditto, well bathed with fluid *after* potass.
....	*Solut. nitr. pot.*	℈j to ℥j.	......	6 sec.	30 sec.	Well bathed with solut. nitr. potass and water then added, the solution allowed to remain.
....	Solut. nitr. pot.	......	......	5 sec.	30 sec.	
....	*Acetic acid.*	ʒj to ℥j.	5 sec.	......	20 sec.	Impregnating fluid applied quickly and profusely, and water then added.
....	Acetic acid.	ʒj to ℥j.	5 sec.	......	20 sec.	
Solut. *gum-arab.*	....	......	15 sec.	......	1^m	Water was added quickly after the gum, but not sufficient to remove it; one or two ova segmented.
Solut. gum-arab.	....	......	15 sec.	......	1^m	
....	*Solut. caust. pot.*	*gr. viij to ℥j.*	......	5 sec.	35 sec.	No. 1 to 8 of this set also removed at end of nineteen hours to high temperature, 62° Fahr., No. 1 and 2 being thoroughly bathed with seminal fluid.
....	Solut. caust. pot.	*℈j to ℥j.*	......	2 sec.	45 sec.	
....	Solut. caust. pot.	Weak.	......	2 sec.	45 sec.	Water added and solut. of potass not washed off.
....	Solut. caust. pot.	Strong.	......	1 sec.	62 sec.	Nearly the whole at twenty hours spoiled.
....	Solut. caust. pot.	Weak.	2 sec.	......	50 sec.	
....	Solut. caust. pot.	Strong.	1 sec.	......	45 sec.	All spoiled in a few hours.
....	*Solut. nitr. pot.*	gr. viij to ℥j.	......	1 sec.	30 sec.	Ova passed on a moist surface and *well bathed* with fluid.
....	*Acetic acid dilut.*	......	......	1 sec.	45 sec.	
Solut. *gum-arab.*	....	......	1 sec.	......	1^m	This was a thick solution of gum and applied with difficulty, but freely and quickly; the eggs were then well bathed with fluid and allowed to remain in a low, and slightly diminishing temperature.
Solut. gum-arab.	....	......	1 sec.	......	45 sec.	
....	*Solut. caust. pot.*	Strong.	......	1 sec.	15 sec.	Ova touched lightly for an instant only with the fecundating fluid, and water afterwards added.
....	Solut. caust. pot.	Strong.	......	2 sec.	20 sec.	
....	Solut. caust. pot.	Strong.	1 sec.	......	15 sec.	Time of applying the potass was from two to three seconds; the eggs were spoiling within twenty minutes.
....	Solut. caust. pot.	Strong.	1 sec.	......	12 sec.	
....	....	......	......	......	......	Made with *fecundating fluid* without solution of potass to test the above.
....	*Solut. nitr. pot.*	Strong.	......	1 sec.	20 sec.	These ova were passed on a dry surface and were then thoroughly bathed with seminal fluid and water.
....	Solut. nitr. pot.	Strong.	......	3 sec.	25 sec.	
....	Solut. nitr. pot.	Strong.	3 sec.	......	20 sec.	The fluid was applied *after* the solution.
Solut. gum-arab.	....	......	......	2 sec.	20 sec.	Impregnation must thus have occurred very quickly.
Solut. gum-arab.	....	......	2 sec.	......	20 sec.	
....	....	......	......	......	......	Made to test the fecundatory fluid at *two hours* after mixture with water.
....	....	......	......	......	......	Not one egg segmented or one embryo found.
Solut. gum-arab.	....	......	3 sec.	......	......	Gum applied thickly and the ova then bathed with fecundating fluid.
Solut. of starch.	....	......	10 sec.	......	......	The ova *passed into* the starch, and a large quantity of fluid then added.
Solut. of starch.	....	......	10 sec.	......	......	Ova passed on a dry surface, starch applied with a pencil.
Solut. of starch.	....	......	......	2 sec.	16^m	Changed to fresh water after sixteen minutes.

abdomen. It does not return to the centre of the yelk, nor escape to the surface, but is lost much nearer to the latter than to the former position; and its disappearance is the result of the endogenous development of cells in its interior. The egg is cast loose into the abdomen, and then consists only of the yelk mass in its vitelline membrane, and it is transferred to the mouth of the oviduct by the joint action of the abdominal muscles and the motions of the viscera, and not necessarily through the aid of the male during copulation. *Second,* changes are going on in the constituents of the egg, both before and after oviposition as well in the unimpregnated as in the impregnated condition; but they soon cease in the former, and do not proceed to the cleaving or segmentation of the yelk. *Third,* that the egg is not susceptible of impregnation until after it has acquired the envelopes which it gains in the oviduct. *Fourth,* that endosmosis of the entire egg takes place through these envelopes, and is most rapid during the few minutes the egg is most susceptible of impregnation. Further, that this endosmosis is augmented and hastened by an increase, and is lessened and retarded by a diminution of temperature; and that the susceptibility of the egg to become impregnated, and produce, is in exactly the same condition with regard to heat; whether the egg be exposed to, or whether it be excluded from light. *Fifth,* that only extremely minute granules of solid matter can by any possibility pass into the tissue of the envelopes during endosmosis; and that there is no evidence whatever of the existence of a fissure or orifice, in the envelopes of the egg of the Amphibia, at the time of, or before impregnation, capable of admitting the spermatozoon to the interior of the yelk-membrane or its contents. *Sixth,* that it is the spermatozoon alone which effects impregnation; and that this does not take place until the spermatozoon is brought into immediate contact with the external envelopes of the ovum. *Seventh,* that the *liquor seminis,* when entirely separated from spermatozoa, certainly does not effect impregnation. *Eighth,* that although direct contact of the spermatozoa with the ovum is indispensable to effect impregnation, I have never been able to detect any traces of these bodies in contact with the yelk-membrane, or even within the substance of the external envelope. *Ninth,* that impregnation is *commenced* the instant the spermatozoa are brought into contact with the egg, but a certain *duration of contact* is essential to its completion. *Tenth,* that impregnation is not effected when the whole or the majority of the spermatozoa in contact with the envelopes have previously become motionless and, apparently, have lost vitality, as they are found to have done after the lapse of a longer or shorter period. *Eleventh,* that although an exceedingly minute quantity of spermatozoa suffice to impregnate the ovum, the phenomenon of impregnation takes place more tardily, even with duration of contact when the number is extremely limited, than when it is in full abundance, without excess; while when the quantity is deficient, or the duration of contact too limited, then the phenomenon is incomplete, and partial impregnation only is effected. *Twelfth, partial impregnation* is shown in imperfect segmentation of the yelk; and is due chiefly to the spermatozoa being insufficient in quantity, or in duration of contact, or inefficient through diminished vitality; and it may also result from diminished susceptibility in the ovum. *Thirteenth,* partial impregnation of the ovum is of frequent occurrence, as I found in my first experiments with fluid that had passed through filtering-paper, but which still contained a very few spermatozoa, either motionless or exceedingly feeble; and further, partial impregnation is of much the most frequent occurrence when the ova are placed in dense fluid before contact with the spermatozoa, as in the experiments with carmine. *Lastly*, when the ova are only partially impregnated they are usually, and perhaps always unproductive.

These facts lead us to inquire, whether impregnation takes place through any catalytic influence of the spermatozoa as suggested by Bischoff*, while in a state of activity, and at the instant they are brought into contact with the ovum, or whether impregnation results from a diffluence of the spermatozoa thus brought into contact with the surface, the substance into which they may be dissolved being carried by endosmosis with the water imbibed through the tissues; or whether it is the result of the conjoint influence of both these conditions;—the first action induced being instantaneous and catalytic, and possibly dependent on the persistence of organic vitality in the spermatozoa, while the completion of the impregnation may depend on the imbibition of some material influence or substance derived from the impregnating body;—a view which the gradual disappearance of the bodies of the spermatozoa from the surface of the ovum, both in the Frog and Newt, seems to favour; as we have already seen that endosmosis is an active and important function of the envelopes of the ovum at the very period when impregnation is effected.

All the experiments now detailed seem to show that in those vertebrata which expel their ova into water before impregnation, as in the tail-less *Amphibia*, and in which—from the nature of the medium into which the ova are passed—we may infer that the function takes place most quickly, impregnation is commenced at the very instant of contact of the spermatozoon with the ovum, and even may be completed within very short spaces of time—but *duration* of at least some seconds of actual contact,—even in these animals' ova, is essential to the perfection of the function;—but this period, we may fairly conclude, may differ in different classes of animals, and possibly may have some relation to the greater or less facility with which the spermatozoa are brought into contact with the ova.

When the experiments last detailed are compared,—the effects produced by the application of media which influence the spermatozoon and the ovum chemically,—with those of which the effect is merely mechanical, we seem to have made some advance towards a future knowledge of the nature of the impregnating power. Although we are as yet entirely without proof that any material influence or substance is actually transmitted from the spermatozoon on the surface of the ovum to the yelk in the interior, we have evidence that fluids are imbibed by the ovum by endosmosis through its tissues; and although not a trace of the spermatozoon is detected in the interior of the ovum, we have seen that it remains for a long time on the surface, and gradually disappears, apparently by diffluence; so that it may be fair to conclude, that the agency of this body is material in its operation. On the other hand, the effect which we find is produced on the yelk by the direct and even momentary contact of the

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* Müller's Archives, 1847.

spermatozoon with the envelopes of the ovum, seems closely to resemble that of the so-called catalytic power of certain known bodies, in so far as that contact, during only very short spaces of time, with the surface of the ovum, appears to be sufficient to induce certain changes in the interior. These changes, too, as known of catalysis, are carried only to a certain extent when the exciting agents,—in this instance the spermatozoa,—are feeble in action or but very few in number; and then, as we have seen, the yelk may become only more or less partially segmented; or the changes in it, having proceeded to a certain extent, may then become arrested, apparently from deficiency of the originally exciting cause. Then, again, we find that although segmentation of the yelk may take place, embryos are not produced unless there has been some continuance or duration of contact of the impregnating with the impregnated body; and that the number produced seems to have reference to the duration and to the full sufficiency of the exciting cause. But neither what we at present know of the so-called catalytic power or of endosmosis, appears alone to be sufficient to account for the whole of the phenomena of impregnation. Simple contact of the spermatozoon does not appear to be sufficient to determine the transmission of more or less of the material structural characters of the male parent to the offspring; while diffluence and endosmosis of the substance of the spermatozoon can hardly be imagined to occur in a brief second or two of time sufficiently to effect the full impregnation of the yelk, and induce its invariable consequence, segmentation. Possibly, we may hereafter find that the first changes induced by contact of the impregnating body are completed by its diffluence, and by the material constituents into which it is dissolved, being transferred to the yelk by endosmosis.

Description of the Plate.

PLATE XIV.

Fig. 1. The female Frog, *Rana temporaria*, dissected to show the situation of the entrance to the oviducts (*a*) at each side of the heart (*b*). The liver (*c*) is drawn back and removed a little from its natural position to show the spaces (*d*) along which the ova pass from the cavity of the abdomen to the mouths of the oviducts (*g*), to be received into the dilated or uterine portion of the ducts (*h*). (*i.*) The stomach. (*k.*) Intestine. (*l.*) Colon and rectum. (*m.*) The bladder.

Fig. 2. A portion of the commencement of the oviduct magnified, partially concealed by the root of the lung.

a. The entrance to the duct between the heart and liver. (*e.*) The suspensory ligament of the liver. (*f.*) The base of the lung around which the oviduct (*g*) passes.

Fig. 3. The female Frog, exhibiting the viscera *in situ* before the ova have left the ovaries (*p*) and with the oviducts (*g*) enlarged with secretion, for the formation of the envelopes of the ova as they pass through to the uterine or dilated portions of the ducts (*h*).

Fig. 4. The female Frog after oviposition, with the organs of digestion and the liver removed to show the condition of the ovaries (*p*) with their fatty appendages (*q*), the hyoid and thyroid muscles (*n*) (*o*) (*p*), the lungs (*f*) and the contracted state of the oviducts (*g*), and their uterine enlargement (*h*) with the rectum (*l*), and the bladder (*m*) then beginning again to be enlarged.

Fig. 5. Structure of the ovarian ovum.

a. The ovum while still attached to the inner surface of the ovary and projecting into the cavity, exhibiting the dark surface within the ovisac, which is traversed by minute vessels (*b*).

Fig. 6. Vertical section of the ovum, showing the situation of the germinal vesicle and the canal in the yelk, which corresponds to the centre of the dark surface of the yelk.

Fig. 7. The presumed mode of disappearance of the vesicle.

Fig. 8. Spermatozoa of the Frog. *a* and *b* escaping from the vesicle of development, *c*, as seen on the egg after contact.

Fig. 9. An ovum with spermatozoa half an hour after impregnation.

Fig. 10. A small portion of surface of the yelk at the commencement of segmentation, highly magnified. (*a*.) Yelk-cells at the same period. (*b*.) The smaller cells of the last, more highly magnified.

Figs. 11 and 12. Examples of partial impregnation at twenty-eight hours after contact with the spermatozoa.

X. *A Mathematical Theory of Magnetism. By* William Thomson, *Esq., M.A., F.R.S.E., Fellow of St. Peter's College, Cambridge, and Professor of Natural Philosophy in the University of Glasgow. Communicated by Lieut.-Colonel* Sabine, *R.A., For. Sec. R.S.*

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Introduction.

1. THE existence of magnetism is recognized by certain phenomena of force which are attributed to it as their cause. Other physical effects are found to be produced by the same agency; as in the operation of magnetism with reference to polarized light, recently discovered by Mr. Faraday; but we must still regard magnetic force as the characteristic of magnetism, and, however interesting such other phenomena may be in themselves, however essential a knowledge of them may be for enabling us to arrive at any satisfactory ideas regarding the physical nature of magnetism, and its connection with the general properties of matter, we must still consider the investigation of the laws, according to which the development and the action of magnetic force are regulated, to be the primary object of a Mathematical Theory in this branch of Natural Philosophy.

2. Magnetic bodies, when put near one another, in general exert very sensible mutual forces; but a body which is not magnetic, can experience no force in virtue of the magnetism of bodies in its neighbourhood. It may indeed be observed that a body, M, will exert a force upon another body A; and again, on a third body B; although when A and B are both removed to a considerable distance from M, no mutual action can be discovered between themselves: but in all such cases A and B are, when in the neighbourhood of M, temporarily magnetic; and when both are under the influence of M at the same time, they are found to act upon one another with a mutual force. All these phenomena are investigated in the mathematical theory of magnetism, which therefore comprehends two distinct kinds of magnetic action:—the mutual forces exercised between bodies possessing magnetism, and the magnetization induced in other bodies through the influence of magnets. The First Part of this paper is confined to the more *descriptive* and *positive* details of the subject, with reference to the former class of phenomena. After a sufficient foundation has been laid in it, by the mathematical exposition of the distribution of magnetism in bodies, and by the determination and expression of the general laws of magnetic force, a Second Part will be devoted to the theory of magnetization by influence, or magnetic induction.

FIRST PART.—ON MAGNETS, AND THE MUTUAL FORCES BETWEEN MAGNETS.

Chapter I. *Preliminary Definitions and Explanations.*

3. A magnet is a substance which intrinsically possesses magnetic properties.

A piece of loadstone, a piece of magnetized steel, a galvanic circuit, are examples of the varieties of natural and artificial magnets at present known; but a piece of soft iron, or a piece of bismuth temporarily magnetized by induction, cannot, in unqualified terms, be called a magnet.

A galvanic circuit is frequently, for the sake of distinction, called an "electro-magnet;" but, according to the preceding definition of a magnet, the simple term, without qualification, may be applied to such an arrangement. On the other hand, a piece of apparatus consisting of a galvanic coil, with a soft iron core, although often called simply "an electro-magnet," is in reality a complex arrangement involving an electro-magnet (which is intrinsically magnetic as long as the electric current is sustained) and a body transiently magnetized by induction.

4. In the following analysis of magnets, the magnetism of every magnetic substance considered, will be regarded as absolutely permanent under all circumstances. This condition is not rigorously fulfilled either for magnetized steel or for loadstone, as the magnetism of any such substance is always liable to modification by induction, and may therefore be affected either by bringing another magnet into its neighbourhood, or by breaking the mass itself and separating the fragments. When, however, we consider the magnetism of any fragment taken from a steel or loadstone magnet, the hypothesis will be that it retains without any alteration the magnetic state which it actually had in its position in the body. The general theory of the distribution of magnetism founded upon conceptions of this kind, will be independent of the truth or falseness of any such hypothesis which may be made for the sake of convenience in studying the subject; but of course any actual experiments in illustration of the analysis or synthesis of a magnet would be affected by a want of *rigidity* in the magnetism of the matter operated on. For such illustrations, electro-magnets are extremely appropriate, as in them, except during the motion by which any alteration in their form or arrangement is effected, no appreciable inductive action can exist.

5. In selecting from the known phenomena of magnetism those elementary facts which are to serve for the foundation of the theory, all complex actions, depending on the irregularities of the bodies made use of, should be excluded. Thus if we were to attempt an experimental investigation of the action between two amorphous fragments of loadstone, or between two pieces of steel magnetized by ordinary processes, we should probably fail to recognize the simple laws on which the actions, resulting from such complicated circumstances, depend; and we must look for a simpler case of magnetic action before we can make an analysis which may lead to the establishment of the fundamental principles of the theory. Much complication will be avoided if we take a case in which the irregularities of one at least of the bodies do not affect the phenomena to be considered. Now the earth, as was first shown by Gilbert, is a magnet; and its dimensions are so great that there is no sensible

variation in its action on different parts of any ordinary magnet upon which we can experiment, and consequently, in the circumstances, no complicacy depending on the actual distribution of terrestrial magnetism. We may therefore, with advantage, commence by examining the action which the earth produces upon a magnet of any kind at its surface.

6. At a very early period in the history of magnetic discovery, the remarkable property of "pointing north and south" was observed to be possessed by fragments of loadstone and magnetized steel needles. To form a clear conception of this phenomenon, we must consider the total action produced by the earth upon a magnet of any kind, and endeavour to distinguish between the effects of gravitation which the earth exerts upon the body in virtue of its weight, and those which result from the magnetic agency.

7. In the first place, it is to be remarked that the magnetic agency of the earth gives rise to no resultant force of sensible magnitude, upon any magnet with reference to which we can perform experiments, as is proved by the following observed facts.

(1.) A magnet placed in any manner, and allowed to move with perfect freedom in any horizontal direction (by being floated, for example, on the surface of a liquid), experiences no action which tends to set its centre of gravity in motion, and there is therefore no horizontal force upon the body.

(2.) The magnetism of a body may be altered in any way, without affecting its weight as indicated by a balance. Hence there can be no vertical force upon it depending on its magnetism.

8. It follows that any magnetic action which the earth can exert upon a magnet must be a couple. To ascertain the manner in which this action takes place, let us conceive a magnet to be supported by its centre of gravity* and left perfectly free to turn round this point, so that without any constraint being exerted which could balance the magnetic action, the body may be in circumstances the same as if it were without weight. The magnetic action of the earth upon the magnet gives rise to the following phenomena:—

(1.) The body does not remain in equilibrium in every position in which it may be brought to rest, as it would do did it experience no action but that of gravitation.

(2.) If the body be placed in a position of equilibrium, there is a certain axis (which, for the present, we may conceive to be found by trial), such, that if the body be turned round it, through any angle, and be brought to rest, it will remain in equilibrium.

(3.) If the body be turned through 180°, about an axis perpendicular to this, it will again be in a position of equilibrium.

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* The ordinary process for finding experimentally the centre of gravity of a body, fails when there is any magnetic action to interfere with the effects of gravitation. It is, however, for our present purpose, sufficient to know that the centre of gravity exists; that is, that there is a point such that the vertical line of the resultant action of gravity passes through it, in whatever position the body be held. If it were of any consequence, a process, somewhat complicated by the magnetic action, for actually determining, by experiment, the centre of gravity of a magnet might be indicated, and thus the experimental treatment of the subject in the text would be completed.

(4.) Any motion of the body whatever, which is not of either of the kinds just described, nor compounded of the two, will bring it into a position in which it will not be in equilibrium.

(5.) The directing couple experienced by the body in any position depends solely on the angle of inclination of the axis described in (1.) to the line along which it lies when the body is in equilibrium; being independent of the position of the plane of this angle, and of the position of the body with reference to that axis.

9. From these observations we draw the conclusion that a magnet always experiences a directing couple from the earth, unless a certain axis in the body is placed in a determinate position. This line in the body is called its magnetic axis*.

10. The direction towards which the magnetic axis of the body tends in virtue of the earth's action, is called "the line of dip," or "the direction of the total terrestrial magnetic force," at the locality of the observation.

11. No further explanation regarding phenomena which depend on terrestrial magnetism is required in the present chapter; but, as the facts have been stated in part, it may be right to complete the statement, as far as regards the action experienced by a magnet of any kind when held in different positions in a given locality, by mentioning the following conclusions, deduced in a very obvious manner from the general laws of magnetic action stated below, and verified fully by experiment.

If a magnet be held with its magnetic axis inclined at any angle to the line of dip, it will experience a couple, the moment of which is proportional to the sine of the angle of inclination, acting in a plane containing the magnetic axis and the line of dip. The position of equilibrium towards which this couple tends to bring the magnetic axis is stable, and if the direction of the magnetic axis be reversed, the body may be left balanced, but it will be in unstable equilibrium.

12. The directive tendency observed in magnetic bodies, being found to depend on their geographical position, and to be related in some degree to the terrestrial poles, received the name of *polarity*; probably on account of a false hypothesis of forces exercised by the pole-star† or by the earth's poles, upon certain points of the loadstone or needle, thence called the "poles of the magnet." The terms "polarity" and "poles" are still retained, but the use of them which has very generally been made, is nearly as vague as the ideas from which they had their origin. Thus when the magnet is an elongated mass, its ends are called poles if its magnetic axis be in the direction of its length; no definite points, such as those in which the surface of the body is cut by the magnetic axis, being precisely indicated by the term as it is

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* Any line in the body parallel to this might, with as good reason, be called a magnetic axis, but when we conceive the magnet to be supported by its centre of gravity, the magnetic axis is naturally taken as a line through this point.

† In the poem of Guiot de Provence (quoted in WHEWELL's History of the Inductive Sciences, vol. ii. p. 46), a needle is described as being magnetized and placed in or on a straw (floating on water it is to be presumed)—

"Puis se torne la pointe toute
Contre l'estoile sans doute."

generally used. If, however, the body be symmetrical about its magnetic axis, and symmetrically magnetized, whether elongated in that direction or not, the poles might be definitely the *ends of the magnetic axis* (or the points in which the surface is cut by it), unless the magnet be annular and not cut by its magnetic axis (a ring electro-magnet, for instance), in which case the ordinary conception of *poles* fails. Notwithstanding this vagueness, however, the terms poles and polarity are extremely convenient, and, with the following explanations, they will frequently be made use of in this paper.

13. Let O be any point in a magnet, and let N O S be a straight line parallel to the line defined above as the magnetic axis through the centre of gravity. If the point O, however it has been chosen, be called the centre of the magnet, the line N S, terminated either at the surface, on each side, or in any arbitrary manner, is called the magnetic axis, and the ends, N, S, of the magnetic axis are called the poles of the magnet[*].

14. That pole (marked N) which points, on the whole, from the north, and in northern latitudes upwards, is called the north pole, and the other (S), which points from the south, is called the south pole.

15. The *sides* of the body towards its north pole and south pole, are said to possess "northern polarity" and "southern polarity" respectively, an expression obviously founded on the idea that the surface of a magnet may in general be contemplated as a locus of poles.

16. If a magnetic body be broken up into any number of fragments, each morsel is found to be a complete magnet, presenting in itself all the phenomena of poles and polarity. This property is generally contemplated when, in modern writings on physical subjects, polarity is mentioned as a property belonging to a solid body; and a corresponding idea is involved in the term when it is applied with reference to the electric state which Mr. Faraday discovered to be induced in non-conductors of electricity ("dielectric"), when subjected to the influence of electrified bodies[†]. However different are the physical circumstances of magnetic and electric polarity, it appears that the positive laws of the phenomena are the same[‡], and therefore the mathematical theories are identical. Either subject might be taken as an example of a very important branch of physical mathematics, which might be called "A Mathematical Theory of Polar Forces."

17. Although we have seen that any magnet, in general, experiences from the earth an action subject to certain very simple laws, yet the actual distribution of the magnetism which it possesses may be extremely irregular. We may certainly conceive

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[*] A definition of poles at variance with this is adopted in some special cases, especially in that of the earth considered as a great magnet, but the manner in which the term will be used in this paper will be such as to produce no confusion on this account.

[†] Faraday's Experimental Researches in Electricity, Eleventh Series.

[‡] See a paper "On the Elementary Laws of Statical Electricity," published in the Cambridge and Dublin Mathematical Journal (vol. i.) in December 1845.

that if the magnetized substance be a regular crystal of magnetic iron ore, the magnetism is distributed through it according to some simple law; but by taking an amorphous and heterogeneous fragment of ore presenting magnetic properties, by magnetizing in any way an irregular mass of steel, by connecting any number of morsels of magnetic matter so as to make up a complex magnet, or by bending a galvanic wire into any form, we may obtain magnets in which the magnetic property is distributed in any arbitrary manner, however irregular. Excluding for the present the last-mentioned case, let us endeavour to form a conception of the distribution of magnetism in actually magnetized matter, such as steel or loadstone, and to lay down the principles according to which it may in any instance be mathematically expressed.

18. In general we may consider a magnet as composed of matter which is magnetized throughout, since, in general, it is found that any fragment cut out of a magnetic mass is itself a magnet possessing properties entirely similar to those which have been described as possessed by any magnet whatever. It may be however that a small portion cut out of a certain position in a magnet, may present no magnetic phenomena; and if we cut equal and similar portions from different positions, we may find them to possess magnetic properties differing to any extent both in intensity, and in the directions of their magnetic axes.

19. If we find that equal and similar portions, cut in parallel directions, from any different positions in a given magnetic mass, possess equal and similar magnetic properties, the mass is said to be uniformly magnetized.

20. In general, however, the intensity of magnetization must be supposed to vary from one part to another, and the magnetic axes of the different parts to be not parallel to one another. Hence, to lay down determinately a specification of the distribution of magnetism through a magnet of any kind, we must be able to express the *intensity* and the *direction* of magnetization at each point. Before attempting to define a standard for the numerical expression of intensity in magnetization, it will be convenient to examine the elementary laws upon which the phenomena of magnetic force depend, since it is by these effects that the nature and energy of the *magnetism* to which they are due must be estimated.

Chapter II. *On the Laws of Magnetic Force, and on the Distribution of Magnetism in Magnetized Matter.*

21. The object of the elementary magnetic researches of Coulomb was the determination of the mutual action between two infinitely thin, uniformly and longitudinally magnetized bars. The magnets which he used were in strictness neither uniformly nor longitudinally magnetized, such a state being unattainable by any actual process of magnetization; but, as the bars were very thin cylindrical steel wires, and were symmetrically magnetized, the resultant actions were sensibly the same as if they were in reality infinitely thin, and longitudinally magnetized; and from experi-

ments which he made, it appears that the intensity of the magnetization must have been very nearly constant from the middle of each of the bars, to within a short distance from either end, where a gradual decrease of intensity is sensible*.

22. These circumstances having been attended to, COULOMB was able to deduce from his experiments the true laws of the phenomena, and arrived at the following conclusions:—

(1.) If two thin uniformly and longitudinally magnetized bars be held near one another, an action is exerted between them which consists of four distinct forces, along the four lines joining their extremities.

(2.) The forces between like ends of the two bars are repulsive†.

(3.) The forces between unlike ends are attractive.

(4.) If the bars be held so that the four distances between their extremities, two and two, are equal, the four forces between them will be equal.

(5.) If the relative positions of the bars be altered, each force will vary inversely as the square of the mutual distance of the poles between which it acts.

23. To establish a standard for estimating the *strength* of a magnet, let us conceive two infinitely thin bars to be placed so that either end of one may be a unit of distance from an end of the other. Then, if the bars be equally magnetized, each uniformly and longitudinally, to such a degree that the force between those ends shall be unity, the strength of each bar-magnet is unity‡.

24. If any number, m, of such unit bars, of equal length, be put with like ends together, so as to constitute a single complex bar, the strength of the magnet so formed is denoted by m.

If there be any number of thin bar-magnets of equal length, and each of them of such a strength that q of them, with like ends together, would constitute a unit-bar; and if p of those bars be put with like ends together, the strength of the complex magnet so formed will be $\frac{p}{q}$.

25. If a single infinitely thin bar be magnetized to such a degree that in the same positions it would produce the same effects as a complex bar of any strength m (an integer or fraction), the strength of this magnet is denoted by m.

26. If two complex bar-magnets, of the kind described above, be put near one an-

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* See note on § 38, below.

† Hence we see the propriety of the terms *north* and *south* applied to the opposite polarities of a magnet, as explained above. Thus we designate the polarity, or the imaginary magnetic matter, of the northern and southern magnetic hemispheres of the earth, as northern and southern respectively; and since the poles of ordinary magnets which are repelled by the earth's northern or southern polarity must be *similar*, these also are called northern or southern, as the case may be.

‡ The Royal Society in its Instructions for making observations on Terrestrial Magnetism adopts one foot as the unit of length; and, that force which, if acting on a grain of matter, would in one second of time generate one foot per second of velocity, as the unit of force; which is consequently very nearly $\frac{1}{32\cdot2}$ of the weight, in any part of Great Britain or Ireland, of one grain.

other, each bar of one will act on each bar of the other with the same forces as if all the other bars were removed. Hence, if the distance between the two poles be unity, and if the strengths of the bars be respectively m and m', (whether these numbers be integral or fractional,) the force between those poles will be mm'. If, now, the relative position of the magnets be altered, so that the distance between two poles may be f, the force between them will, according to Coulomb's law, be

$$\frac{m m'}{f^2}.$$

According to the definition given above of the strength of a simple bar-magnet, it follows that the same expression gives the force between two poles of any thin, uniformly and longitudinally magnetized bars, of strengths m and m'.

27. The *magnetic moment* of an infinitely thin, uniformly and longitudinally magnetized bar, is the product of its length into its strength.

28. If any number of equally strong, uniformly and longitudinally magnetized rectangular bars of equal infinitely small sections, be put together, with like ends towards the same parts, a complex uniformly magnetized solid of any form may be produced. The *magnetic moment* of such a magnet is equal to the sum of the magnetic moments of the bars of which it is composed.

29. The magnetic moment of any continuous solid, uniformly magnetized in parallel lines, is equal to the sum of the magnetic moments of all the thin, uniformly and longitudinally magnetized bars into which it may be divided.

It follows that the magnetic moment of any part of a uniformly magnetized mass is proportional to its volume.

30. The *intensity of magnetization* of a uniformly magnetized solid is the magnetic moment of a unit of its volume.

It follows that the magnetic moment of a uniformly magnetized solid, of any form and dimensions, is equal to the product of its volume into the intensity of its magnetization.

31. If a body be magnetized in any arbitrary, regular or irregular manner, a portion may be taken in any position, so small in all its dimensions that the distribution of magnetism through it will be sensibly uniform. The quotient obtained by dividing the magnetic moment of such a portion, in any position P, by its volume, is the *intensity of magnetization* of the substance at the point P; and a line through P parallel to its lines of magnetization, is the *direction of magnetization*, at P.

Chapter III. *On the Imaginary Magnetic Matter by means of which the Polarity of a Magnetized Body may be represented.*

32. It will very often be convenient to refer the phenomena of magnetic force to attractions or repulsions mutually exerted between portions of an imaginary magnetic matter, which, as we shall see, may be conceived to represent the polarity of a magnet of any kind. This imaginary substance possesses none of the primary qualities

of ordinary matter, and it would be wrong to call it either a solid, or the "magnetic fluid," or "fluids"; but, without making any hypothesis whatever, we may call it "magnetic matter," on the understanding that it possesses only the property of attracting or repelling magnets, or other portions of "matter" of its own kind, according to certain determinate laws, which may be stated as follows:—

(1.) There are two kinds of imaginary magnetic matter, northern and southern, to represent respectively the northern and southern magnetic polarities of the earth, or the similar polarities of any magnet whatever.

(2.) Like portions of magnetic matter repel and unlike portions attract, mutually.

(3.) Any two small portions of magnetic matter exert a mutual force which varies inversely as the square of the distance between them.

(4.) Two units of magnetic matter, at a unit of distance from one another, exert a unit of force, mutually.

33. If quantities of magnetic matter be measured numerically in such units, and if the positive or negative sign be prefixed to denote the *species* of matter, whether *northern* (which, by convention, we may call *positive*) or *southern*, all the preceding laws are expressed in the following proposition:—

If quantities, m *and* m', *of magnetic matter be concentrated respectively at points at a distance,* f, *from one another, they will repel with a force algebraically equal to*

$$\frac{m m'}{f^2}.$$

34. It appears from the explanations given above, that the circumstances of a uniformly magnetized needle may be represented if we imagine equal quantities of northern and southern magnetic matter to be concentrated at its two poles, the numerical measure of these equal quantities being the same as that of the "strength" of the magnet.

The mutual action between two needles would thus be reduced to forces of attraction and repulsion between the portions of magnetic matter by which their poles are represented.

35. Any magnetic mass whatever may, as we have seen, be regarded as composed of infinitely small bar-magnets put together in such a way as to produce the distribution of magnetism which it actually possesses; and hence, by replacing the poles of these magnets by imaginary magnetic matter, we obtain a distribution of equal quantities of northern and southern magnetic matter through the magnetized substance, by which its actual magnetic condition may be represented. The distribution of this matter becomes very much simplified from the circumstance that we have in general unlike poles of the elementary magnets in contact, by which the opposite kinds of magnetic matter are partially (or in a class of cases *wholly**) destroyed through the interior of the body. The determination of the resulting distribution of

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* In all cases when the distribution is "solenoidal." See below, Chap. V. § 68. Communicated to the Royal Society, June 20, 1850.

magnetic matter, which represents in the simplest possible manner the polarity of any given magnet, is of much interest, and even importance, in the theory of magnetism, and we may therefore make this an object of investigation, before going farther.

36. Let it be required to find the distribution of imaginary magnetic matter to represent the polarity of any number of uniformly magnetized needles, $S_1 N_1, S_2 N_2, \ldots S_n N_n$ of strengths $\mu_1, \mu_2, \ldots \mu_n$ respectively, when they are placed together, end to end (not necessarily in the same straight line).

If A denote the position occupied by S_1 when the bars are in their places; if N_1 and S_2 are placed in contact at K_1; N_2 and S_3, at K_2; and so on until we have the last magnet, with its end S_n, in contact with N_{n-1}, at K_{n-1}, and its other end, N_n, free, at a point B; we shall have to imagine

μ_1 units of southern magnetic matter to be placed at A;
μ_1 units of northern, and μ_2 units of southern matter at K_1;
μ_2 units of northern, and μ_3 of southern matter at K_2;
. . . .
μ_{n-1} units of northern, and μ_n of southern matter at K_{n-1};
and lastly, μ_n units of northern matter at B.

Hence the final distribution of magnetic matter is as follows:—

$-\mu_1$ . . . . at A
$\mu_1 - \mu_2$ . . . . K_1
$\mu_2 - \mu_3$ . . . . K_2
. . . .
. . . .
$\mu_{n-1} - \mu_n$ . . . . K_{n-}
and μ_n . . . . B.

37. The complex magnet $AK_1K_2 \ldots K_{n-1}B$ consists of a number of parts, each of which is uniformly and longitudinally magnetized, and it will act in the same way as a simple bar of the same length, similarly magnetized; and hence the magnetic matter which represents a bar-magnet AB of this kind is concentrated in a series of points, at the ends of the whole bar, and at all the places where there is a variation in the strength* of its magnetization.

38. If the length of each part through which the strength of the magnetism is constant, be diminished without limit, and if the entire number of the parts be increased indefinitely, a straight or curved infinitely thin bar may be conceived to be produced, which shall possess a distribution of longitudinal magnetism varying continuously from one end to the other according to any arbitrary law. If the strength of the magnetism at any point P of this bar be denoted by μ, and if $[\mu]$ and (μ) denote

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* This expression is equivalent to *the product of the intensity of magnetization into the section of the bar*; and by retaining it we are enabled to include cases in which the bar is not of uniform section.

the values of μ at the points A and B, the investigation of § 36, with the elementary principles and notation of the differential calculus, leads at once to the determination of the ultimate distribution of magnetic matter by which such a bar-magnet may be represented. Thus if AP be denoted by s; μ will be a function of s, which may be supposed to be known, and its differential coefficient will express the continuous distribution of magnetic matter which replaces the group of material points at K_1, K_2, &c.; so that the entire distribution of polarity in the bar and at its ends will be as follows:—in any infinitely small length, σ, of the bar, a quantity of matter equal to

$$-\frac{d\mu}{ds}\cdot\sigma,$$

and, besides, terminal accumulations, of quantities

$$-[\mu] \text{ at A}$$

and

$$(\mu) \text{ at B.}$$

It follows that if through any part of the length of a bar, the strength of the magnetism is constant, there will be no magnetic matter to be distributed through this portion of the magnet; but if the strength of the magnetism varies, then, according as it diminishes or increases from the north to the south pole of any small portion, there will be a distribution of northern or southern magnetic matter to represent the polarity which results from this variation.

Corresponding inferences may be made conversely, with reference to the distribution of magnetism, when the distribution of the imaginary magnetic matter is known. Thus Coulomb found that his long thin cylindrical bar-magnets acted upon one another as if each had a symmetrical distribution of the two kinds of magnetic matter, northern within a limited space from one end, and southern within a limited space from the other, the intermediate space (constituting generally the greater part of the bar) being unoccupied; from which we infer that no variation in the magnetism was sensible through the middle part of the bar, but that, through a limited space on each side, the intensity of the magnetization must have decreased gradually towards the ends*.

39. The distribution of magnetic matter which represents the polarity of a uniformly magnetized body of any form, may be immediately determined if we imagine

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* This circumstance was alluded to above, in § 21. Interesting views on the subject of the distribution of magnetism in bar-magnets are obtained by taking arbitrary examples to illustrate the investigation of the text. Thus we may either consider a uniform bar variably magnetized, or a thin bar of varying thickness, cut from a uniformly magnetized substance; and according to the arbitrary data assumed, various remarkable results may be obtained. We shall see afterwards that any such data, however arbitrary, may be actually produced in electro-magnets, and we have therefore the means of illustrating the subject experimentally, in as complete a manner as can be conceived, although from the practical *non-rigidity* of the magnetism of magnetized substances, ordinary steel or loadstone magnets would not afford such satisfactory illustrations of *arbitrary* cases as might be desired. The distribution of longitudinal magnetism in steel needles actually magnetized in different ways, and especially "magnetized to saturation," has been the object of interesting experimental and theoretical investigations by Coulomb, Biot, Green and Riess.

it divided into infinitely thin bars, in the directions of its lines of magnetization; for each of these bars will be uniformly and longitudinally magnetized, and therefore there will be no distribution of matter except at their ends. Now the bars are all terminated on each side by the surface of the body, and consequently the whole magnetic effect is represented by a certain superficial distribution of northern and southern magnetic matter. It only remains to determine the actual form of this distribution; but, for the sake of simplicity in expression, it will be convenient to state previously the following definition, borrowed from COULOMB's writings on electricity.

40. If any kind of matter be distributed over a surface, the *superficial density* at any point is the quotient obtained by dividing the quantity of matter on an infinitely small element of the surface in the neighbourhood of that point, by the area of the element.

41. To determine the superficial density at any point in the case at present under consideration, let ω be the area of the perpendicular section of an infinitely thin uniform bar, of the solid, with one end at that point. Then, if i be the intensity of magnetization of the solid, $i\omega$ will be, as may be readily shown, the "strength" of the bar-magnet. Hence at the two ends of the bar we must suppose to be placed quantities of northern and southern imaginary magnetic matter each equal to $i\omega$. In the distribution over the surface of the given magnet, these quantities of matter must be imagined to be spread over the oblique ends of the bar. Now if θ denote the inclination of the bar to a normal to the surface through one end, the area of that end will be $\frac{\omega}{\cos\theta}$, and therefore in that part of the surface we have a quantity of matter equal to $i\omega$ spread over an area $\frac{\omega}{\cos\theta}$. Hence the superficial density is

$$i\cos\theta.$$

This expression gives the superficial density at any point, P, of the surface, and its algebraic sign indicates the kind of matter, provided the angle denoted by θ be taken between the external part of the normal, and a line drawn from P in the same direction as that of the motion of a point carried from the south pole, to the north pole, of a portion close to P, of the infinitely thin bar-magnet which we have been considering.

42. Let it be required, in the last place, to determine the entire distribution of magnetic matter necessary to represent the polarity of any given magnet.

We may conceive the whole magnetized mass to be divided into infinitely small parallelepipeds by planes parallel to three planes of rectangular coordinates. Let α, β, γ denote the three edges of one of these parallelepipeds having its centre at a point P (x, y, z). Let i denote the given intensity, and l, m, n the given direction cosines of the magnetization at P. It will follow from the preceding investigation that the polarity of this infinitely small, uniformly magnetized parallelepiped, may be represented by imaginary magnetic matter distributed over its six faces in such a manner that the density will be uniform over each face, and that the quantities of matter on the six faces will be as follows:—

$-il\,.\,\beta\gamma$, and $il\,.\,\beta\gamma$; on the two faces parallel to YOZ;
$-im\,.\,\gamma\alpha$, and $im\,.\,\gamma\alpha$; on the two faces parallel to ZOX;
$-in\,.\,\alpha\beta$, and $in\,.\,\alpha\beta$; on the two faces parallel to XOY.

Now if we consider adjacent parallelepipeds of equal dimensions, touching the six faces of the one we have been considering, we should find from each of them a second distribution of magnetic matter, to be placed upon that one of those six faces which it touches. Thus if we consider the first face $\beta\gamma$, or that of which the distance from YOZ is $x-\frac{1}{2}\alpha$; we shall have a second distribution upon it derived from a parallelepiped the coordinates of the centre of which are $x-\alpha, y, z$; and the quantity of matter in this second distribution will be

$$\left\{il+\frac{d(il)}{dx}(-\alpha)\right\}\beta\gamma.$$

This, added to that which was found above, gives

$$\frac{d(il)}{dx}(-\alpha)\,.\,\beta\gamma, \text{ or } -\frac{d(il)}{dx}\,.\,\alpha\beta\gamma$$

for the total amount of matter upon this face. Again, the quantity in the second distribution on the other face, $\beta\gamma$, is equal to

$$-\left\{il+\frac{d(il)}{dx}\,.\,\alpha\right\}\beta\gamma,$$

and therefore the total amount of matter on this face will be

$$-\frac{d(il)}{dx}\,.\,\alpha\beta\gamma.$$

By determining in a similar way the final quantities of matter on the other faces of the parallelepiped, we find that the total amount of matter to be distributed over its surface is

$$-2\left\{\frac{d(il)}{dx}+\frac{d(im)}{dy}+\frac{d(in)}{dz}\right\}\alpha\beta\gamma.$$

Now as the parallelepipeds into which we imagine the whole mass divided are infinitely small, we may substitute a continuous distribution of matter through them, in place of the superficial distributions on their faces which have been determined; and in making this substitution, the quantity of matter which we must suppose to be spread through the interior of any one of them must be half the total quantity on its surface, since each of its faces is common to it and another parallelepiped. Hence the quantity of matter to be distributed through the parallelepiped $\alpha\beta\gamma$ is equal to

$$-\left\{\frac{d(il)}{dx}+\frac{d(im)}{dy}+\frac{d(in)}{dz}\right\}\alpha\beta\gamma.$$

Besides this continuous distribution through the interior of the magnet, there must be a superficial distribution to represent the neutralized polarity at its surface. If ϱ denote the density of this distribution at any point; $[l]$, $[m]$, $[n]$ the direction cosines, and $[i]$ the intensity of the magnetization of the solid close to it; and λ, μ, ν the direction cosines of a normal to the surface, we shall have, as in the case of the uniformly magnetized solid previously considered,

$$\varrho=[i]\cos\theta=[il].\lambda+[im].\mu+[in].\nu \quad \ldots\ldots\ldots\ldots \quad (1).$$

If, according to the usual definition of "density," k denote the density of the magnetic matter at P, in the continuous distribution through the interior, the expression found above for the quantity of matter in the element α, β, γ, leads to the formula

$$k=-\left\{\frac{d(il)}{dx}+\frac{d(im)}{dy}+\frac{d(in)}{dz}\right\}. \quad \ldots\ldots\ldots\ldots \quad (2).$$

These two equations express respectively the superficial distribution, and the continuous distribution through the solid, of the magnetic matter which entirely represents the polarity of the given magnet. The fact that the quantity of northern matter is equal to the quantity of southern in the entire distribution, is readily verified by showing from these formulæ, as may readily be done by integration, that the total quantity of matter is algebraically equal to nothing.

43. If there be an abrupt change in the intensity or direction of the magnetization from one part of the magnetized substance to another, a slight modification in the formulæ given above will be convenient. Thus we may take a case differing very little from a given case, but which instead of presenting finite differences in the intensity or direction of magnetization, on the two sides of any surface in the substance of the magnet, has merely very sudden continuous changes in the values of those elements: we may conceive the distribution to be made more and more nearly the same as the given distribution, with its abrupt transitions, and we may determine the limit towards which the value of the expression (2) approximates, and thus, although according to the ordinary rules of the differential calculus this formula fails in the limiting case, we may still derive the true result from it. It is very easily shown in this way, that, besides the continuous distribution given by the expression (2) applied to all points of the substance for which it does not fail, there will be a superficial distribution of magnetic matter on any surface of discontinuity; and that the density of this superficial distribution will be the difference between the products of the intensity of magnetization into the cosine of the inclination of its direction to the normal, on the two sides of the surface.

44. This result, obtained by the interpretation of formula (2) in the extreme case, might have been obtained directly from the original investigation, by taking into account the abrupt variation of the magnetization at the surface of discontinuity, as we did the abrupt termination of the magnetized substance at the boundary of the magnet, and representing the un-neutralized polarity which results, by a superficial distribution of magnetic matter.

CHAPTER IV. *Determination of the Mutual Actions between any Given Portions of Magnetized Matter.*

45. The synthetical part of the theory of magnetism has for its ultimate object the determination of the total action between two magnets, when the distribution of magnetism in each is given. The principles according to which the data of such a problem may be specified have been already laid down (§§ 28–31.), and we have seen that, with sufficient data in any case, COULOMB's laws of magnetic force are sufficient to enable us to apply ordinary statical principles to the solution of the problem. Hence the elements of this part of the theory may be regarded as complete, and we may proceed to the mathematical treatment of the subject.

46. The investigations of the preceding chapter, which show us how we may conventionally represent any given magnet, in its agency upon other bodies, by an imaginary magnetic matter distributed on its surface and through its interior; enable us to reduce the problem of finding the action between any two magnets, to the known problem of determining the resultant of the attractions or repulsions exerted between the particles of two groups of matter, according to the law of force which is met with so universally in natural phenomena. The direct formulæ applicable for this object are so readily obtained by means of the elementary principles of statics, and so well known, that it is unnecessary to cite them here, and we may regard equations (1) and (2) of the preceding chapter (§ 42.) as sufficient for indicating the manner in which the details of the problem may be worked out in any particular case. The expression for the "potential," and other formulæ of importance in LAPLACE's method of treating this subject, are given below (§ 51.), as derived from the results expressed in equations (1) and (2).

47. The preceding solution of the problem, although extremely simple and often convenient, must be regarded as very artificial, since in it the resultant action is found by the composition of mutual actions between the particles of an imaginary magnetic matter, which are not the same as the real mutual actions between the different parts of the magnets themselves, although the resultant action between the entire groups of matter is necessarily the same as the real resultant action between the entire magnets. Hence it is very desirable to investigate another solution, of a less artificial form, in which the required resultant action may be obtained by compounding the real actions between the different parts into which we may conceive the magnets to be divided. The remainder of the chapter, after some preliminary explanations and definitions, will be devoted to this object.

48. The "resultant magnetic force at any point" is an expression which will very frequently be employed in what follows, and it is therefore of importance that its signification should be clearly defined. For this purpose, let us consider separately the cases of an external point in the neighbourhood of a magnet, and a point in space which is actually occupied by magnetic matter.

(1.) The resultant force at a point in space, void of magnetized matter, is the force that the north pole of a unit-bar (or a positive unit of imaginary magnetic matter), if placed at this point, would experience.

(2.) The resultant force at a point situated in space occupied by magnetized matter, is an expression the signification of which is somewhat arbitrary. If we conceive the magnetic substance to be removed from an infinitely small space round the point, the preceding definition would be applicable; since, if we imagine a very small bar-magnet to be placed in a definite position in this space, the force upon either end would be determinate. The circumstances of this case are made clear by considering the distribution of imaginary magnetic matter required to represent the given magnet, without the small portion we have conceived to be removed from its interior; which will differ from the distribution that represents the entire given magnet, in wanting the small portion of the continuous interior distribution corresponding to the removed portion, and in having instead a superficial distribution on the small internal surface bounding the hollow space. If we consider the portion removed to be infinitely small, the want of the small portion of the *solid* magnetic matter will produce no finite effect upon any point; but the superficial distribution at the boundary of the hollow space will produce a finite force upon any magnetic point within it. Hence the resultant force upon the given point round which the space was conceived to be hollowed, may be regarded as compounded of two forces, one due to the polarity of the complete magnet, and the other to the superficial polarity left free by the removal of the magnetized substance*. The former component is the force meant by the expression "the resultant force at a point within a magnetic substance," when employed in the present paper†.

49. The conventional language and ideas with reference to the imaginary magnetic

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* If the portion removed be spherical and infinitely small, it may be proved that the force at any point within it, resulting from the free polarity of the solid at the surface bounding the hollow space, is in the direction of the lines of magnetization of the substance round it, and is equal to $\frac{4\pi i}{3}$. This theorem (due to POISSON) will be demonstrated at the commencement of the Theory of Magnetic Induction, because we shall have to consider the "magnetizing force" upon any small portion of an inductively magnetized substance as the actual resultant force that would exist within the hollow space that would be left if the portion considered were removed, and the magnetism of the remainder constrained to remain unaltered.

† If we imagine a magnet to be divided into two parts by any plane passing through the line of magnetization at any internal point, P, and if we imagine the two parts to be separated by an infinitely small interval and a unit north pole to be placed between them at P, the force which this pole would experience is "the resultant force at a point, P, of the magnetic substance." This is the most direct definition of the expression that could have been given, and it agrees with the definition I have actually adopted; but I have preferred the explanation and statement in the text, as being practically more simple, and more directly connected with the various investigations in which the expression will be employed.

[Note added June 15, 1850.—Some subsequent investigations on the comparison of common magnets and electro-magnets have altered my opinion, that the definition in the text is to be preferred; and I now believe the definition in the note to present the subject in the simplest possible manner, and in that which, for the applications to be made in the continuation of this Essay, is most convenient on the whole.]

matter, explained above (§§ 32–44), enable us to give the following simple statement of the definition, including both the cases which we have been considering.

The resultant magnetic force at any point, whether in the neighbourhood of a magnet or in its interior, is the force that a unit of northern magnetic matter would experience if it were placed at that point, and if all the magnetized substance were replaced by the corresponding distribution of imaginary magnetic matter.

50. The determination of the resultant force at any point is, as we shall see, much facilitated by means of a method first introduced by LAPLACE in the mathematical treatment of the theory of attraction, and developed to a very remarkable extent by GREEN in his "Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism" (Nottingham, 1828), and in his other writings on the same and on allied subjects in the Cambridge Philosophical Transactions, and in the Transactions of the Royal Society of Edinburgh. LAPLACE's fundamental theorem is so well known that it is unnecessary to demonstrate it here; but for the sake of reference, the following enunciation of it is given. The term "potential," defined in connection with it, was first introduced by GREEN in his Essay (1828). It was at a later date introduced independently by GAUSS, and is now in very general use.

Theorem (LAPLACE).—The resultant force produced by a body, or a group of attracting or repelling particles, upon a unit particle placed at any point P, is such that the difference between the values of a certain function, at any two points p and p' infinitely near P, divided by the distance pp', is equal to its component in the direction of the line joining p and p'.

Definition (GREEN).—This function, which, for a given mass, has a determinate value at any point, P, of space, is called the potential of the mass, at the point P.

It follows from the general demonstration, that, when the law of force is that of the inverse square of the distance, the potential is found by dividing the quantity of matter in any infinitely small part of the mass, by its distance from P, and adding all the quotients so obtained.

51. The same demonstration is applicable to prove, in virtue of COULOMB's fundamental laws of magnetic force, the same theorem with reference to any kind of magnet that can be conceived to be composed of uniformly magnetized bars, either finite or infinitely small, put together in any way, that is, of any magnet other than an electro-magnet; and the investigation, in the preceding chapter, of the resulting distribution of magnetic matter that may be imagined as representing in the simplest possible way the polarity of such a magnet, enables us to determine at once, from equations (1) and (2) of § 42, its potential at any point. Thus if V denote the potential at a point P, whose coordinates are ξ, η, ζ, and if dS denote an element of the surface of the magnet, situated at a point whose coordinates are $[x]$, $[y]$, $[z]$, we have, by the proposition enunciated at the end of § 49,—

$$V=\iint\frac{[il]\lambda+[im]\mu+[in]\nu}{[\Delta]}dS-\iiint\frac{\frac{d(il)}{dx}+\frac{d(im)}{dy}+\frac{d(in)}{dz}}{\Delta}dxdydz, \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where Δ and $[\Delta]$ are respectively the distances of the points x, y, z and $[x, y, z]$ from the point P, and are given by the equations

$$\Delta^2=(\xi-x)^2+(\eta-y)^2+(\zeta-z)^2$$

$$[\Delta]^2=(\xi-[x])^2+(\eta-[y])^2+(\zeta-[z])^2.$$

The double and triple integrals in the first and second terms of this expression are to be taken respectively over the whole surface bounding the magnet, and throughout the entire magnetized substance. Since, as is easily shown, the value of that portion of the triple integral in the second member which corresponds to an infinitely small portion of the solid containing (ξ, η, ζ), when this point is internal, is infinitely small, it follows that the magnetic force at any internal point, as defined in § 48, is derivable from a potential expressed by equation (3).

52. The expressions for the resultant force at any point, and its direction, may be immediately obtained when the potential function has been determined, by the rules of the differential calculus. Thus, if V has been determined in terms of the rectangular coordinates, ξ, η, ζ, of the point P, the three components, X, Y, Z, of the resultant force on this point will be given, in virtue of LAPLACE's fundamental theorem enunciated in § 50, by the formulæ,

$$X=-\frac{dV}{d\xi}, \quad Y=-\frac{dV}{d\eta}, \quad Z=-\frac{dV}{d\zeta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4),$$

where the negative signs are introduced, because the potential is estimated in such a way that it diminishes in the direction along which a north pole is urged. If we take the expression (3) for V, and actually differentiate with reference to ξ, η, ζ under the integral signs, we obtain expressions for X, Y, and Z which agree with the expressions that might have been obtained directly, by means of the first principles of statics (see § 46), and thus the theorem is verified. Such a verification, extended so as to be applicable to a body acting according to any law of force, constitutes virtually the ordinary demonstration of the theorem.

53. The formulæ of the preceding paragraphs are applicable for the determination of the potential, and the resultant force at any point, whether within the magnetized substance or not, according to the general definition of § 49. The case of a point in the magnetized substance, according to the conventional second definition of § 48, cannot present itself in problems with reference to the mutual action between two actual magnets. This case being therefore excluded, we may proceed to the investigations indicated in § 47.

54. In the method which is now to be followed, the magnetized substances considered must be conceived to be divided into an infinite number of infinitely small parts, and the actual magnetism of each part will be taken into account, whether in determining the potential of the magnet at a given external point, or in investigating the mutual action between two magnets. In the first place, let us determine the potential due to an infinitely small element of a magnetized substance, and for this purpose we may commence by considering an infinitely thin, uniformly magnetized

bar of finite length. If m denote the strength of the bar, and if N and S be its north and south poles respectively, its potential at any point, P, will be, according to §§ 34 and 50,

$$\frac{m}{\mathrm{NP}}-\frac{m}{\mathrm{SP}}.$$

Let Δ denote the distance of the point of bisection of the bar from P, and θ the angle between this line and the direction of the bar measured from its centre towards its north pole. Then, if a be the length of the bar, the expression for the potential becomes

$$m\left\{\frac{1}{(\Delta^2-a\Delta\cos\theta+\frac{1}{4}a^2)^{\frac{1}{2}}}-\frac{1}{(\Delta^2+a\Delta\cos\theta+\frac{1}{4}a\ )^{\frac{1}{2}}}\right\}.$$

By expanding this in ascending powers of a, and neglecting all the terms after the first, we find for the potential of an infinitely small bar magnet,

$$\frac{ma\cos\theta}{\Delta^2}.$$

If now we suppose any number of such bar-magnets to be put together so as to constitute a mass magnetized in parallel lines, infinitely small in all its dimensions, the values of θ and Δ, and consequently the value of $\frac{\cos\theta}{\Delta^2}$, will be infinitely nearly the same for all of them, and the product of this into the sum of the values of ma for all the bar-magnets will express the potential of the entire mass. Hence, if the total magnetic moment be denoted by μ, the potential will be equal to

$$\frac{\mu\cos\theta}{\Delta^2}.$$

Now if we conceive the bars to have been arranged so as to constitute a uniformly magnetized mass, occupying a volume ϕ, we should have (§ 30.) for the intensity of magnetization, $i=\frac{\mu}{\phi}$. Hence if ϕ denote the volume of an infinitely small element of uniformly magnetized matter, and i the intensity of its magnetization, the potential which it produces at any point P, at a finite distance from it, will be

$$\frac{i\phi.\cos\theta}{\Delta^2},$$

where Δ denotes the distance of P from any point, E, within the element, and θ the angle between E P and a line drawn through E, in the direction of magnetization of the element, *towards the side of it which has northern polarity.*

55. Let us now suppose the element E to be a part of a magnet of finite dimensions, of which it is required to determine the total potential at an external point, P. Let ξ, η, ζ be the coordinates of P, referred to a system of rectangular axes, and let x, y, z be those of E. We shall have

$$\Delta^2=(\xi-x)^2+(\eta-y)^2+(\zeta-z)^2;$$

and, if l, m, n denote the direction cosines of the magnetization at E,

$$\cos\theta = l\frac{\xi-x}{\Delta}+m\frac{\eta-y}{\Delta}+n\frac{\zeta-z}{\Delta}.$$

Hence the expression for the potential of the element E becomes

$$\frac{i\phi\{l(\xi-x)+m(\eta-y)+n(\zeta-z)\}}{\{(\xi-x)^2+(\eta-y)^2+(\zeta-z)^2\}^{\frac{3}{2}}}.$$

Now the potential of a whole is equal to the sum of the potentials of all its parts, and hence, if we take $\phi=dx\,dy\,dz$, we have, by the integral calculus, the expression,

$$V=\iiint\frac{il.(\xi-x)+im.(\eta-y)+in.(\zeta-z)}{\{(\xi-x)^2+(\eta-y)^2+(\zeta-z)^2\}^{\frac{3}{2}}}dxdydz \quad . \; . \; . \; . \; . \; . \; . \; . \quad (5);$$

for the potential at the point P, due to the entire magnet*.

56. This expression is susceptible of a very remarkable modification, by integration by parts. Thus we may divide the second member into three terms, of which the following is one:

$$\iiint\frac{il.(\xi-x)dx}{\{(\xi-x)^2+(\eta-y)^2+(\zeta-z)^2\}^{\frac{3}{2}}}dydz.$$

Integrating here by parts, with reference to x, we obtain

$$\left[\iint\frac{il.dy\,dz}{\Delta}\right]-\iiint\frac{\frac{d(il)}{dx}}{\Delta}dxdydz,$$

where the brackets enclosing the double integral denote that the variables in it must belong to some point of the surface. If λ, μ, ν denote the direction cosines of a normal to the surface at any point $[\xi, \eta, \zeta]$, and dS an element of the surface, we may take $dy\,dz=\lambda.dS$, and hence the double integral is reduced to

$$\iint\frac{[il]\lambda.dS}{[\Delta]};$$

and, as we readily see by tracing the limits of the first integral with reference to x, for all possible values of y and z this double integral must be extended over the entire surface of the magnet. By treating in a similar manner the other two terms of the preceding expression for V, we obtain, finally,

$$V=\iint\frac{[il]\lambda+[im]\mu+[in]\nu}{[\Delta]}dS-\iiint\frac{\frac{d(il)}{dx}+\frac{d(im)}{dy}+\frac{d(in)}{dz}}{\Delta}dxdydz.$$

The second member of this equation is the expression for the potential of a certain complex distribution of matter, consisting of a superficial distribution, and a continuous internal distribution. The superficial-density of the distribution on the surface, and the density of the continuous distribution at any internal point, are expressed respectively by $[il]\lambda+[im]\mu+[in]\nu$, and $-\left\{\frac{d(il)}{dx}+\frac{d(im)}{dy}+\frac{d(in)}{dz}\right\}$. Hence we infer that the action of the complete magnet upon any external point is the same as would be produced by a certain distribution of imaginary magnetic matter, determinable by means of these expressions, when the actual distribution of magnetism in the magnet is given*. The demonstration of the same theorem, given above (§ 42), illustrates in a very interesting manner the process of integration by parts applied to a triple integral.

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* From the form of definition given in the second foot-note on § 48, for the magnetic force at an internal point, it may be shown that the expression (5), as well as the expression (3), is applicable to the potential at any point, whether internal or external. The same thing may be shown by proving, as may easily be done, that the investigation of § 56 does not fail or become nugatory when (ξ, η, ζ) is included in the limits of integration.

57. The mutual action of any two magnets, considered as the resultant of the mutual actions between the infinitely small elements into which we may conceive them to be divided, consists of a force and a couple of which the components will be expressed by means of six triple integrals. Simpler expressions for the same results may be obtained by employing a notation for subsidiary results derived from triple integration with reference to one of the bodies, in the following manner.

58. Let us in the first place determine the action exerted by a given magnet, upon an infinitely thin, uniformly and longitudinally magnetized bar, placed in a given position in its neighbourhood.

We may suppose the rectangular coordinates, ξ, η, ζ, of the north pole, and ξ', η', ζ' of the south pole of the bar to be given, and hence the components, X, Y, Z and X′, Y′, Z′, of the resultant forces, at those points, due to the other given magnet, may be regarded as known. Then, if β denote the "strength" of the bar-magnet, the components of the forces on its two poles will be respectively,

$$\beta X,\ \beta Y,\ \beta Z, \text{ on the point } (\xi, \eta, \zeta),$$

and

$$-\beta X',\ -\beta Y',\ -\beta Z', \text{ on the point } (\xi', \eta', \zeta').$$

The resultant action due to this system of forces may be determined by means of the elementary principles of statics. Thus if we conceive the forces to be transferred to the middle of the bar by the introduction of couples, the system will be reduced to a force, on this point, whose components are

$$\beta(X-X'),\quad \beta(Y-Y'),\quad \beta(Z-Z'),$$

and a couple, whose components are

$$\left\{\beta(Z+Z')\cdot\tfrac{1}{2}(\eta-\eta')-\beta(Y+Y')\cdot\tfrac{1}{2}(\zeta-\zeta')\right\},$$

$$\left\{\beta(X+X')\cdot\tfrac{1}{2}(\zeta-\zeta')-\beta(Z+Z')\cdot\tfrac{1}{2}(\xi-\xi')\right\},$$

$$\left\{\beta(Y+Y')\cdot\tfrac{1}{2}(\xi-\xi')-\beta(X+X')\cdot\tfrac{1}{2}(\eta-\eta')\right\}.$$

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* This very remarkable theorem is due to POISSON, and the demonstration, as it has been just given in the text, is to be found in his first memoir on Magnetism. The demonstration which I have given in § 42 may be regarded as exhibiting, by the theory of polarity, the physical principles expressed in the analytical formulæ.

59. If l, m, n denote the direction cosines of a line drawn along the bar, from its middle towards its north pole, and if a be the length of the bar, we shall have

$$\xi-\xi'=al, \quad \eta-\eta'=am, \quad \zeta-\zeta'=an.$$

Hence, if the bar be infinitely short, and if x, y, z denote the coordinates of its middle point, we have

$$\mathrm{X}-\mathrm{X}'=\frac{d\mathrm{X}}{dx}\,.\,al+\frac{d\mathrm{X}}{dy}\,.\,am+\frac{d\mathrm{X}}{dz}\,.\,an,$$

$$\mathrm{Y}-\mathrm{Y}'=\frac{d\mathrm{Y}}{dx}\,.\,al+\frac{d\mathrm{Y}}{dy}\,.\,am+\frac{d\mathrm{Y}}{dz}\,.\,an,$$

and

$$\mathrm{Z}-\mathrm{Z}'=\frac{d\mathrm{Z}}{dx}\,.\,al+\frac{d\mathrm{Z}}{dy}\,.\,am+\frac{d\mathrm{Z}}{dz}\,.\,an.$$

Multiplying each member of these equations by β, we obtain the expressions for the components of the force in this case; and the expressions for the components of the couples are found in their simpler forms, by substituting for $\xi-\xi'$, &c. their values given above; and, on account of the infinitely small factor which each term contains, taking $2\mathrm{X}$, $2\mathrm{Y}$, and $2\mathrm{Z}$, in place of $\mathrm{X}+\mathrm{X}'$, $\mathrm{Y}+\mathrm{Y}'$, and $\mathrm{Z}+\mathrm{Z}'$.

60. Let us now suppose an infinite number of such infinitely small bar-magnets to be put together so as to constitute a mass, infinitely small in all its dimensions, uniformly magnetized in the direction (l, m, n) to such an intensity that its magnetic moment is μ. We infer, from the preceding investigation, that the total action on this body, when placed at the point x, y, z, will be composed of a force whose components are

$$\mu\left(\frac{d\mathrm{X}}{dx}l+\frac{d\mathrm{X}}{dy}m+\frac{d\mathrm{X}}{dz}n\right),$$

$$\mu\left(\frac{d\mathrm{Y}}{dx}l+\frac{d\mathrm{Y}}{dy}m+\frac{d\mathrm{Y}}{dz}n\right),$$

$$\mu\left(\frac{d\mathrm{Z}}{dx}l+\frac{d\mathrm{Z}}{dy}m+\frac{d\mathrm{Z}}{dz}n\right),$$

acting at the centre of gravity of the solid supposed homogeneous; and a couple of which the components are

$$\mu(\mathrm{Z}m-\mathrm{Y}n),$$

$$\mu(\mathrm{X}n-\mathrm{Z}l),$$

$$\mu(\mathrm{Y}l-\mathrm{X}m).$$

61. The preceding investigation enables us, by means of the integral calculus, to determine the total mutual action between any two given magnets. For, if we take X, Y, Z to denote the components of the resultant force due to one of the magnets, at any point (x, y, z) of the other, and if i denote the intensity and (l, m, n) the direction of magnetization of the substance of the second magnet at this point, we may take $\mu=i\,.\,dxdydz$ in the expressions which were obtained, and they will then express

the action which one of the magnets exerts upon an element *dxdydz* of the other. To determine the total resultant action, we may transfer all the forces to the origin of coordinates, by introducing additional couples; and, by the usual process, we find, for the mutual action between the two magnets, a force in a line through this point, and a couple, of which the components, F, G, H, and L, M, N, are given by the equations

$$\left.\begin{aligned}
\mathrm{F}&=\iiint\left(il\frac{d\mathrm{X}}{dx}+im\frac{d\mathrm{X}}{dy}+in\frac{d\mathrm{X}}{dz}\right)dxdydz\\
\mathrm{G}&=\iiint\left(il\frac{d\mathrm{Y}}{dx}+im\frac{d\mathrm{Y}}{dy}+in\frac{d\mathrm{Y}}{dz}\right)dxdydz\\
\mathrm{H}&=\iiint\left(il\frac{d\mathrm{Z}}{dx}+im\frac{d\mathrm{Z}}{dy}+in\frac{d\mathrm{Z}}{dz}\right)dxdydz
\end{aligned}\right\}\quad\ldots\ldots\ldots\ldots\quad(6)$$

$$\left.\begin{aligned}
\mathrm{L}&=\iiint\left\{im\mathrm{Z}-in\mathrm{Y}+y\left(il\frac{d\mathrm{Z}}{dx}+im\frac{d\mathrm{Z}}{dy}+in\frac{d\mathrm{Z}}{dz}\right)-z\left(il\frac{d\mathrm{Y}}{dx}+im\frac{d\mathrm{Y}}{dy}+in\frac{d\mathrm{Y}}{dz}\right)\right\}dxdydz\\
\mathrm{M}&=\iiint\left\{in\mathrm{X}-il\mathrm{Z}+z\left(il\frac{d\mathrm{X}}{dx}+im\frac{d\mathrm{X}}{dy}+in\frac{d\mathrm{X}}{dz}\right)-x\left(il\frac{d\mathrm{Z}}{dx}+im\frac{d\mathrm{Z}}{dy}+in\frac{d\mathrm{Z}}{dz}\right)\right\}dxdydz\\
\mathrm{N}&=\iiint\left\{il\mathrm{Y}-im\mathrm{X}+x\left(il\frac{d\mathrm{Y}}{dx}+im\frac{d\mathrm{Y}}{dy}+in\frac{d\mathrm{Y}}{dz}\right)-y\left(il\frac{d\mathrm{X}}{dx}+im\frac{d\mathrm{X}}{dy}+in\frac{d\mathrm{X}}{dz}\right)\right\}dxdydz
\end{aligned}\right\}\quad(7)$$

62. If, in the second members of these equations, we employ for X, Y, Z respectively their values obtained, as indicated in equations (4) of § 52, by the differentiation of the expression (5) for V in § 55, we obtain expressions for F, G, H, L, M, N, which may readily be put under symmetrical forms with reference to the two magnets, exhibiting the parts of those quantities depending on the mutual action between an element of one of the magnets, and an element of the other. Again, expressions exhibiting the mutual action between any element of the imaginary magnetic matter of one magnet, and any element of the imaginary magnetic matter of the other, may be found by first modifying by integration by parts, as in § 56, from the expressions which we have actually obtained for F, G, H, L, M, N; and then substituting for X, Y, and Z their values obtained by the differentiation of the expression (3) for V.

It is unnecessary here to do more than indicate how such other formulæ may be derived from those given above; for whenever it may be required, there can be no difficulty in applying the principles which have been established in this paper to obtain any desired form of expression for the mutual action between two given magnets.

§§ 63 and 64*. *On the Expression of Mutual Action between two Magnets by means of the Differential Coefficients of a Function of their relative Position.*

63. By a simple application of the theory of the potential, it may be shown that the amount of mechanical work spent or gained in any motion of a permanent magnet, effected under the action of another permanent magnet in a fixed position, depends solely on the initial and final positions, and not at all upon the positions successively occupied by the magnet in passing from one to the other. Hence the amount of work requisite to bring a given magnet from being infinitely distant from all magnetic bodies, into a certain position in the neighbourhood of a given fixed magnet, depends solely upon the distributions of magnetism in the two, and on the relative position which they have acquired. Denoting this amount by Q, we may consider Q as a function of coordinates which fix the relative position of the two magnets; and the variation which Q experiences when this is altered in any way will be the amount of work spent or lost, as the case may be, in effecting the alteration. This enables us to express completely the mutual action between the two magnets, by means of differential coefficients of Q, in the following manner:—

If we suppose one of the magnets to remain fixed during the alterations of relative position conceived to take place, the quantity Q will be a function of the linear and angular coordinates by which the variable position of the other is expressed. Without specifying any particular system of coordinates to be adopted, we may denote by $d_\xi Q$ the augmentation of Q when the moveable magnet is pushed through an infinitely small space $d\xi$ in any given direction, and by $d_\varphi Q$ the augmentation of Q when it is turned round any given axis, through an infinitely small angle $d\varphi$. Then, if F denote the force upon the magnet in the direction of $d\xi$, and L the moment round the fixed axis of all the forces acting upon it (or the component, round the fixed axis, of the resultant couple obtained when all the forces on the different parts of the magnet are transferred to any point on this axis), we shall have

$$-\mathrm{F}d\xi=d_\xi \mathrm{Q}, \quad \text{and} \quad -\mathrm{L}d\varphi=d_\varphi \mathrm{Q},$$

since a force equal to $-\mathrm{F}$ is overcome through the space $d\xi$ in the first case, and a couple, of which the moment is equal to $-\mathrm{L}$, is overcome through an angle $d\varphi$ in the second case of motion. Hence we have

$$\mathrm{F}=-\frac{d_\xi \mathrm{Q}}{d\xi}$$

$$\mathrm{L}=-\frac{d_\varphi \mathrm{Q}}{d\varphi}.$$

64. It only remains to show how the function Q may be determined when the distributions of magnetism in the two magnets and the relative positions of the bodies are

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* Communicated June 20, 1850.

given. For this purpose, let us consider points P and P′, in the two magnets respectively, and let their coordinates with reference to three fixed rectangular axes be denoted by x, y, z and x', y', z'; let also the intensity of magnetization at P be denoted by i, and its direction cosines by l, m, n; and let the corresponding quantities, with reference to P′, be denoted by i', l', m', n'. Then it may be demonstrated without difficulty that

$$Q=\iiiiiint dx\,dy\,dz\,dx'\,dy'\,dz'\,ii'\left\{ll'\frac{d^2\frac{1}{\Delta}}{dx\,dx'}+lm'\frac{d^2\frac{1}{\Delta}}{dx\,dy'}+ln'\frac{d^2\frac{1}{\Delta}}{dx\,dz'},\right.$$
$$+ml'\frac{d^2\frac{1}{\Delta}}{dy\,dx'}+mm'\frac{d^2\frac{1}{\Delta}}{dy\,dy'}+mn'\frac{d^2\frac{1}{\Delta}}{dy\,dz'}$$
$$\left.+nl'\frac{d^2\frac{1}{\Delta}}{dz\,dx'}+nm'\frac{d^2\frac{1}{\Delta}}{dz\,dy'}+nn'\frac{d^2\frac{1}{\Delta}}{dz\,dz'}\right\},$$

where, for brevity, Δ is taken to denote $\{(x-x')^2+(y-y')^2+(z-z')^2\}^{\frac{1}{2}}$, and the differentiations upon $\frac{1}{\Delta}$ are merely indicated. Now, by any of the ordinary formulæ for the transformation of coordinates, the values of x, y, z, and x', y', z', may be expressed in terms of coordinates of the point P with reference to axes fixed in the magnet to which it belongs, of the coordinates of the point P′ with reference to axes fixed in the other, and of the coordinates adopted to express the relative position of the two magnets: and so the preceding expression for Q may be transformed into an expression involving explicitly the relative coordinates, and containing the coordinates of the points P and P′ in the two bodies only as variables in integrations, the limits of which, depending only on the forms and dimensions of the two bodies, are absolutely constant. Thus Q is obtained as a function of the relative coordinates of the bodies, and the solution of the problem is complete.

There is no difficulty in working out the result by this method, so as actually to obtain either the expressions (6) and (7) of § 61, or the expressions indicated in § 62, although the process is somewhat long.

The method just explained for expressing the mutual action between two magnets in terms of a function of their relative position, has been added to this chapter rather for the sake of completing the mathematical theory of the division of the subject to which it is devoted, than for its practical usefulness in actual problems regarding magnetic force, for which the most convenient solutions may generally be obtained by some of the more synthetical methods explained in the preceding parts of the chapter. There is however a far more important application of the principles upon which this last method is founded which remains to be made. The mechanical value of a distribution of magnetism, although it has not, I believe, been noticed in any writings hitherto published on the mathematical theory of magnetism, is a subject of investigation of great interest, and, as I hope on a later occasion to have an opportunity of showing, of much consequence, on account of its maximum and minimum problems, which lead to demonstrations of important theorems in the solutions of inverse problems regarding magnetic distribution.

XI. *A Mathematical Theory of Magnetism.—Continuation of Part* I. *By* WILLIAM THOMSON, *Esq., M.A., F.R.S.E., Fellow of St. Peter's College, Cambridge, and Professor of Natural Philosophy in the University of Glasgow. Communicated by Lieut.-Colonel* SABINE, *For. Sec. R.S.*

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CHAPTER V. *On Solenoidal and Lamellar Distributions of Magnetism.*

65. IN the course of some researches upon inverse problems regarding distributions of magnetism, and upon the comparison of electro-magnets and common magnets, I have found it extremely convenient to make use of definite terms to express certain distributions of magnetism and forms of magnetized matter possessing remarkable properties. The use of such terms will be of still greater consequence in describing the results of these researches, and therefore, before proceeding to do so, I shall give definitions of the terms which I have adopted, and explain briefly the principal properties of the magnetic distributions to which they are applied. The remainder of this chapter will be devoted to three new methods of analysing the expressions for the resultant force of a magnet at any point, suggested by the consideration of these special forms of magnetic distribution. A Mathematical Theory of Electro-Magnets, and Inverse Problems regarding magnetic distributions, are the subjects of papers which I hope to be able to lay before the Royal Society on a subsequent occasion.

66. *Definitions and explanations regarding Magnetic Solenoids.*

(1.) A magnetic solenoid* is an infinitely thin bar of any form, longitudinally magnetized with an intensity varying inversely as the area of the normal section in different parts.

The constant product of the intensity of magnetization into the area of the normal section, is called the magnetic strength, or sometimes simply the strength of the solenoid. Hence the magnetic moment of any straight portion, or of an infinitely small portion of a curved solenoid, is equal to the product of the magnetic strength into the length of the portion.

(2.) A number of magnetic solenoids of different lengths may be put together so as to constitute what is, as far as regards magnetic action, equivalent to a single infinitely thin bar of any form, longitudinally magnetized with an intensity varying arbitrarily from one end of the bar to the other. Hence such a magnet may be called a complex magnetic solenoid.

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* This term (from *σωλὴν, a tube,*) is suggested by the term "electro-dynamic solenoid" applied by AMPÈRE to a certain tube-like arrangement of galvanic circuits which produces precisely the same external magnetic effect as is produced by ordinary magnetism distributed in the manner defined in the text. The especial appropriateness of the term to the magnetic distribution is manifest from the relation indicated in the foot-note on § 76 below, between the intensity and direction of magnetization in a solenoid, and the velocity and direction of motion of a liquid flowing through a tube of constant or varying section.

The magnetic strength of a complex solenoid is not uniform, but varies from one part to another.

(3.) An infinitely thin closed ring, magnetized in the manner described in (1.), is called a closed magnetic solenoid.

67. *Definitions and explanations regarding Magnetic Shells.*

(1.) A magnetic shell is an infinitely thin sheet of any form, normally magnetized with an intensity varying inversely as the thickness in different parts.

The constant product of the intensity of magnetization into the thickness is called the magnetic strength, or sometimes simply the strength of the shell. Hence the magnetic moment of any plane portion, or of an infinitely small portion of a curved magnetic shell, is equal to the product of the magnetic strength, into the area of the portion.

(2.) A number of magnetic shells of different areas may be put together so as to constitute what is, as far as regards magnetic action, equivalent to a single infinitely thin sheet of any form, normally magnetized with an intensity varying arbitrarily over the whole sheet. Hence such a magnet may be called a complex magnetic shell.

The magnetic strength of a complex shell is not uniform, but varies from one part to another.

(3.) An infinitely thin sheet, of which the two sides are closed surfaces, is called a closed magnetic shell.

68. *Solenoidal and Lamellar Distributions of Magnetism.*—If a finite magnet of any form be capable of division into an infinite number of solenoids which are either closed or have their ends in the bounding surface, the distribution of magnetism in it is said to be solenoidal, and the substance is said to be solenoidally magnetized.

If a finite magnet of any form be capable of division into an infinite number of magnetic shells which are either closed or have their edges in the bounding surface, the distribution of magnetism in it is said to be lamellar*, and the substance is said to be lamellarly magnetized.

69. *Complex Lamellar Distributions of Magnetism.*—If a finite magnet of any form be capable of division into an infinite number of complex magnetic shells, it is said to possess a complex lamellar distribution of magnetism.

70. *Complex Solenoidal Distributions of Magnetism.*—Since, by cutting it along

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* The term *lamellar*, adopted for want of a better, is preferred to "laminated"; since this might be objected to as rather meaning "composed of plates," than *composed of shells*, whether plane or curved, and is besides too much associated with a mechanical structure such as that of slate or mica, to be a convenient term for the magnetic distributions defined in the text.

lines of magnetization, every magnet of finite dimensions may be divided into an infinite number of longitudinally magnetized infinitely thin bars or rings, any distribution of magnetism which is not solenoidal might be called a complex solenoidal distribution; but no advantage is obtained by the use of this expression, which is only alluded to here, on account of the analogy with the subject of the preceding definition.

71. Prop.—*The action of a magnetic solenoid is the same as if a quantity of positive or northern imaginary magnetic matter numerically equal to its magnetic strength, were placed at one end, and an equal absolute quantity of negative or southern matter at the other end.*

The truth of this proposition follows at once from the investigation of Chap. III. §§ 36, 37, 38.

Cor. 1.—The action of a magnetic solenoid is independent of its form, and depends solely on its strength and the positions of its extremities.

Cor. 2.—A closed solenoid exerts no action on any other magnet.

Cor. 3.—The " resultant force" (defined in Chap. IV. § 49) at any point in the substance of a closed magnetic solenoid vanishes.

72. Prop.—*If* i *be the intensity of magnetization, and* ω *the area of the normal section at any point* P, *at a distance* s *from one extremity of a complex solenoid, and if* $[\mathrm{i}\omega]$ *and* $\{\mathrm{i}\omega\}$ *denote the values of the product of these quantities at the extremity from which* s *is measured, and at the other extremity respectively; the magnetic action will be the same as if there were a distribution of imaginary magnetic matter, through the length of the bar of which the quantity in an infinitely small portion* ds, *of the length at the point* P, *would be* $-\frac{\mathrm{d}(\mathrm{i}\omega)}{\mathrm{ds}}\mathrm{ds}$, *and accumulations of quantities equal to* $-[\mathrm{i}\omega]$ *and* $\{\mathrm{i}\omega\}$ *respectively at the two extremities.*

The truth of this proposition follows immediately from the conclusions of Chap. III. § 38.

73. Prop.—*The potential of a magnetic shell at any point is equal to the solid angle which it subtends at that point multiplied by its magnetic strength*[*].

Let $d\mathrm{S}$ denote the area of an infinitely small element of the shell, Δ the distance of this element from the point P, at which the potential is considered, and θ the angle between this line, and a normal to the shell drawn through the north polar side of $d\mathrm{S}$. Then if λ denote the magnetic strength of the shell, the magnetic moment of the element $d\mathrm{S}$ will be $\lambda\, d\mathrm{S}$, and (§ 54.) the potential due to it at P will be

$$\frac{\lambda d\mathrm{S}\,.\cos\theta}{\Delta^2}.$$

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[*] This theorem is due to Gauss (see his paper " On the General Theory of Terrestrial Magnetism," § 38; of which a translation is published in Taylor's Scientific Memoirs, vol. ii.). Ampère's well-known theorem, referred to by Gauss, that a closed galvanic circuit produces the same magnetic effect as a magnetic shell of any form having the circuit for its edge, implies obviously the truth of the first part of Cor. 2 below.

Now $\frac{dS \cdot \cos\theta}{\Delta^2}$ is the solid angle subtended at P by the element dS, and therefore the potential due to any infinitely small element is equal to the product of its magnetic strength, into the solid angle which its area subtends at P. But the potential due to the whole is equal to the sum of the potentials due to the parts, and the strength is the same for all the parts. Hence the potential due to the whole shell is equal to the product of its strength into the sum of the solid angles which all its parts, or the solid angle which the whole, subtends at P.

Cor. 1.—The expression $\frac{dS \cdot \cos\theta}{\Delta^2}$, which occurred in the preceding demonstration, being positive or negative according as θ is acute or obtuse, it appears that the solid angles subtended by different parts of the shell at P must be considered as positive or negative according as their north polar or their south polar sides are towards this point.

Cor. 2.—The potential at any point due to a magnetic shell is independent of the form of the shell itself, and depends solely on its bounding line or edge, subject to an ambiguity, the nature of which is made clear by the following statement:—

If two shells of equal magnetic strength, λ, have a common boundary, and if the north polar side of one, and the south polar side of the other be towards the enclosed space, the potentials due to them at any external point will be equal; and the potential at any point in the enclosed space, due to that one of which the northern polarity is on the inside, will exceed the potential due to the other by the constant $4\pi\lambda$.

Cor. 3.—Of two points infinitely near one another on the two sides of a magnetic shell, but not infinitely near its edge, the potential at that one which is on the north polar side exceeds the potential at the other by the constant $4\pi\lambda$.

Cor. 4.—The potential of a closed magnetic shell of strength λ, with its northern polarity on the inside, is $4\pi\lambda$, for all points in the enclosed space, and 0 for all external points; and for points in the magnetized substance it varies continuously from the inside, where it is $4\pi\lambda$ to the outside, where it is 0.

Cor. 5.—A closed magnetic shell exerts no force on any other magnet.

Cor. 6.—The "resultant force" (§ 49.) at any point in the substance of a closed magnetic shell is equal to $\frac{4\pi\lambda}{\tau}$, if τ be the thickness, or to $4\pi i$, if i be the intensity of magnetization of the shell in the neighbourhood of the point, and is in the direction of a normal drawn from the point through the south polar side of the shell.

Cor. 7.—If the intensity of magnetization of an open shell be finite, the resultant force at any external point not infinitely near the edge is infinitely small; but the force at any point in the substance not infinitely near the edge is finite, and is equal to $4\pi i$, if i be the intensity of the magnetization in the neighbourhood of the point, and is in the direction of a normal through the south polar side.

74. Prop.—*A distribution of magnetism expressed by* $\{(\alpha, \beta, \gamma)$ at $(x, y, z)\}$* *is solenoidal if, and is not solenoidal unless* $\frac{d\alpha}{dx}+\frac{d\beta}{dy}+\frac{d\gamma}{dz}=0$.

The condition that a given distribution of magnetism, in a substance of finite dimensions, may be solenoidal, is readily deduced from the investigations of § 42, by means of the propositions of §§ 71 and 72. For, if the distribution of magnetism be solenoidal, the imaginary magnetic matter by which the polarity of the whole magnet may be represented will be situated at the ends of the solenoids, according to § 71, and therefore (§ 68.) will be spread over the bounding surface. On the other hand, if the distribution be not solenoidal, that is, if the magnet be divisible into solenoids, of which some, if not all, are complex; there will, according to § 72, be an internal distribution of imaginary magnetic matter in the representation of the polarity of the whole magnet. Hence it follows from § 42, that if α, β, γ denote the components of the intensity of magnetization at any internal point (x, y, z), the equation

$$\frac{d\alpha}{dx}+\frac{d\beta}{dy}+\frac{d\gamma}{dz}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{I.})$$

expresses that the distribution of magnetism is solenoidal†.

75. Prop.—*A distribution of magnetism* $\{(\alpha, \beta, \gamma)$ at $(x, y, z)\}$ *is lamellar if, and is*

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* Where α, β, γ, which may be called the components, parallel to the axes of coordinates, of the magnetization at (x, y, z), denote respectively the products of the intensity into the direction cosines of the magnetization.

† The analogy between the circumstances of this expression and those of the cinematical condition expressed by "the equation of continuity" to which the motion of a homogeneous incompressible fluid is subject, is so obvious that it is scarcely necessary to point it out. When an incompressible fluid flows through a tube of variable infinitely small section, the velocity (or in reality the mean velocity) in any part is inversely proportional to the area of the section. Hence the intensity and direction of magnetization, in a solenoid, according to the definition, are subject to the same law as the mean fluid velocity in a tube with an incompressible fluid flowing through it. Again, if any finite portion of a mass of incompressible fluid in motion be at any instant divided into an infinite number of solenoids (that is, tube-like parts), by following the lines of motion the velocity in any one of these parts will at different points of it be inversely proportional to the area of its section. Hence the intensity and direction of magnetization in a solenoidal distribution of magnetism, according to the definition, are subject to the same condition as the fluid-velocity and its direction, at any point in an incompressible fluid in motion. It may be remarked, that by making an investigation on the plan of § 42. to express merely the condition that there may be no internal distribution of imaginary magnetic matter, the equation $\frac{d\alpha}{dx}+\frac{d\beta}{dy}+\frac{d\gamma}{dz}=0$ is obtained in a manner precisely similar to a mode of investigating the equation of continuity for an incompressible fluid, now well known, which is given in Duhamel's Cours de Mécanique, and in the Cambridge and Dublin Mathematical Journal, vol. ii. p. 282. The following very remarkable proposition is an immediate consequence of the proposition that "a closed solenoid exerts no action on any other magnet" (§ 71, Cor. 2 above), in virtue of the analogy here indicated.

"If a closed vessel of any internal shape, be completely filled with an incompressible fluid, the fluid set into any possible state of motion, and the vessel held at rest; and if a solid mass of steel of the same shape as the space within the vessel be magnetized at each point with an intensity proportional and in a direction corresponding to the velocity and direction of the motion at the corresponding point of the fluid at any instant; the magnet thus formed will exercise no force on any external magnet."

not lamellar unless $\alpha\mathrm{d}x+\beta\mathrm{d}y+\gamma\mathrm{d}z$ *is the differential of a function of three independent variables.*

Let ψ be a variable which has a certain value for each of the series of surfaces by which the magnet may be divided into magnetic shells; so that, if ψ be considered as a function of x, y, z, any one of these surfaces will be represented by the equation

$$\psi(x, y, z)=\Pi \quad \ldots\ldots\ldots\ldots \quad (a);$$

and the entire series will be obtained by giving the parameter, Π, successively a series of values each greater than that which precedes it by an infinitely small amount. According to the definition of a magnetic shell (§ 67.), the lines of magnetization must cut these surfaces orthogonally; and hence, since α, β, γ denote quantities proportional to the direction cosines of the magnetization at any point, we must have

$$\frac{\alpha}{\frac{d\psi}{dx}}=\frac{\beta}{\frac{d\psi}{dy}}=\frac{\gamma}{\frac{d\psi}{dz}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (b).$$

Let us consider the magnetic shell between two of the consecutive surfaces corresponding to values of the parameter of which the infinitely small difference is ϖ. The thickness of this shell at any point (x, y, z) will be

$$\frac{\varpi}{\left(\frac{d\psi^2}{dx^2}+\frac{d\psi^2}{dy^2}+\frac{d\psi^2}{dz^2}\right)^{\frac{1}{2}}}.$$

Now the product of the intensity of magnetization, into the thickness of the shell, must be constant for all points of the same shell; and hence, since ϖ is constant, and since α, β, γ denote quantities such that $(\alpha^2+\beta^2+\gamma^2)^{\frac{1}{2}}$ is the intensity of magnetization at any point, we must have

$$\frac{(\alpha^2+\beta^2+\gamma^2)^{\frac{1}{2}}}{\left(\frac{d\psi^2}{dx^2}+\frac{d\psi^2}{dy^2}+\frac{d\psi^2}{dz^2}\right)^{\frac{1}{2}}}=\mathrm{F}(\psi) \quad \ldots\ldots\ldots\ldots \quad (c),$$

where $\mathrm{F}(\psi)$ denotes a quantity which is constant when ψ is constant. This equation, and the two equations (b), express all the conditions required to make the given distribution lamellar. By combining them we obtain the following three, which are equivalent to them:—

$$\alpha=\mathrm{F}(\psi)\frac{d\psi}{dx}, \quad \beta=\mathrm{F}(\psi)\frac{d\psi}{dy}, \quad \gamma=\mathrm{F}(\psi)\frac{d\psi}{dz};$$

and hence, if $\int\mathrm{F}(\psi)d\psi$ be denoted by ϕ, we have

$$\alpha=\frac{d\phi}{dx}, \quad \beta=\frac{d\phi}{dy}, \quad \gamma=\frac{d\phi}{dz} \quad \ldots\ldots\ldots\ldots \quad (\text{II.}),$$

where ϕ is some function of x, y and z. Hence the condition that a magnetic distribution (α, β, γ) may be lamellar, is simply that $\alpha dx+\beta dy+\gamma dz$ must be the differential of a function of three independent variables. The equations to express this are obtained in their simplest forms by eliminating the arbitrary function ϕ by differentiation; and are of course

$$\left.\begin{aligned}\frac{d\beta}{dz}-\frac{d\gamma}{dy}=0\\ \frac{d\gamma}{dx}-\frac{d\alpha}{dz}=0\\ \frac{d\alpha}{dy}-\frac{d\beta}{dx}=0\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

Cor.—It follows from the first part of the preceding investigation that equations (*b.*) express that the distribution, if not lamellar, is complex-lamellar. By eliminating the arbitrary function ψ from those equations, (which merely express that $\alpha dx+\beta dy+\gamma dz$ is integrable by a factor,) we obtain the well-known equation

$$\alpha\left(\frac{d\beta}{dz}-\frac{d\gamma}{dy}\right)+\beta\left(\frac{d\gamma}{dx}-\frac{d\alpha}{dy}\right)+\gamma\left(\frac{d\alpha}{dy}-\frac{d\beta}{dx}\right)=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IV.)},$$

as the simplest expression of the condition that α, β, γ must satisfy, in order that the distribution which they represent may be complex-lamellar; and we also conclude that if this equation be satisfied the distribution must be complex-lamellar, unless each term of the first number vanishes by equations (III.) being satisfied, in which case the distribution is, as we have seen, lamellar.

76. The resultant force at any point external to a lamellarly-magnetized magnet will, according to § 73 (Cors. 2 and 4.), depend solely upon the edges of the shells into which it may be divided by surfaces perpendicular to the lines of magnetization (or the bands into which those surfaces cut the bounding surface), and not at all on the forms of these shells, within the bounding surface, nor upon any closed shells of which part of the magnet may consist; and the resultant force at any internal point may (§ 73. Cors. 2, 4, and 7,) be obtained by compounding a force depending solely on those edges, with a force in the direction contrary to that of the magnetization of the substance at the point, and equal to the product of 4π into the intensity of the magnetization. For either an external or an internal point, the resultant force may be expressed by means of a potential, according to § 49; and the value of this potential may be obtained by means of the theorems of § 73, in the following manner.

Let us suppose all the open shells, that is to say all the shells cut by the bounding surface of the given magnet, to be removed, and an imaginary series of shells having the same edges, and the same magnetic strengths, and coinciding with the bounding surface, substituted for them; and, for the sake of definiteness, let us suppose each of these shells to have its north polar side outwards, and to occupy a part of the surface for which the value of ϕ is greater than at its edge. The whole surface will thus be occupied by a series of superimposed magnetic shells, constituting a complex magnetic shell which will produce a potential at any external point the same as that due to the whole of the given magnet; and it will produce a potential at any internal point, which, together with the potential due to the closed shells which surround it, if there are any, and (§ 73, Cor. 2.) together with the product of 4π into the sum of the strengths of any open shells which have it between them and their superficial substitutes, will be the potential due to the whole of the given magnet at this point.

Now if $d\varphi$ denote the difference between the values of φ at two consecutive surfaces of the series, by which we may conceive the whole magnet to be divided into shells, it follows, from the investigation of § 75, that the magnetic strength of the shell is equal to $d\varphi$. Hence, if A denote the least value of φ at any part of the bounding surface, and φ be supposed to correspond to a point in the surface, the strength of the complex magnetic shell, found by adding the strengths of all the shells of the imaginary series superimposed at this point, will be $\varphi - \mathrm{A}$; and if P be an internal point, and the value of φ at it be denoted by (φ), the sum of the strengths of all the shells between that which passes through P and that which corresponds to A, will be $(\varphi)-\mathrm{A}$, from which it may be demonstrated*, that, whether (φ) be $>$ or $<\mathrm{A}$, and whatever be the nature of the shells, whether all open or some open and some closed, the quantity to be added to the potential due to the imaginary complex shell coinciding with the surface of the magnet to find the actual potential at P, is $4\pi\{(\varphi)-\mathrm{A}\}$. Now, from what we have seen above, it follows that the potential at any point P, due to an element, $d\mathrm{S}$, of this complex shell is $\frac{\varphi \, . \cos\theta d\mathrm{S}}{\Delta^2}$, if θ denote the angle which an external normal, or a normal through the north polar side of $d\mathrm{S}$, makes with a line drawn from $d\mathrm{S}$ to P, and Δ the length of this line. Hence the total potential at P, due to the whole complex shell, is equal to

$$\iint \frac{\{\phi+\mathrm{A}\}\cos\theta d\mathrm{S}}{\Delta^2},$$

in which the integration includes the whole bounding surface of the magnet. Hence, if V denote the potential at P, we have the following expression, according as P is external or internal,—

$$\mathrm{V}=\iint \frac{\{\varphi-\mathrm{A}\}\cos\theta d\mathrm{S}}{\Delta^2},$$

or

$$\mathrm{V}=\iint \frac{\{\varphi-\mathrm{A}\}\cos\theta d\mathrm{S}}{\Delta^2}+4\pi\{(\varphi)-\mathrm{A}\}.$$

These expressions may be simplified if we remark that, for any external point,

$$\iint \frac{\cos\theta d\mathrm{S}}{\Delta^2}=0,$$

and that, for any internal point,

$$\iint \frac{\cos\theta d\mathrm{S}}{\Delta^2}=-4\pi$$

(since θ is the angle between the line Δ and the *external* normal through $d\mathrm{S}$). We thus obtain, for an external point,

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* See second foot-note on § 48 above, and Cors. 2, 3, § 76, below.

$$V=\iint\frac{\phi\,.\cos\theta dS}{\Delta^2};$$

and for an internal point,

$$\left.\begin{aligned}&V=\iint\frac{\phi\,.\cos\theta dS}{\Delta^2};\\&V=\iint\frac{\phi\,.\cos\theta dS}{\Delta^2}+4\pi(\phi),\end{aligned}\right\}\quad\ldots\ldots\ldots\quad(V.)$$

Cor. 1.—The potentials at two points infinitely near one another, even if one be in the magnetized substance and the other be external, differ infinitely little; for the value of

$$\iint\frac{\phi\,.\cos\theta dS}{\Delta^2},$$

at a point infinitely near the surface and within it, is found by adding $-4\pi(\phi)$ to the value of the same expression at an external point infinitely near the former.

Cor. 2.—If the value of

$$\iint\frac{\phi\,.\cos\theta dS}{\Delta^2}$$

be denoted by $-Q$ for any internal point, x, y, z; and if $(\alpha), (\beta), (\gamma)$ denote the components of the intensity of magnetization, and X, Y, Z the components of the resultant magnetic force at this point, (that is, according to the definition in the second foot-note on § 48, the force at a point in an infinitely small crevass tangential to the lines of magnetization at x, y, z) we have

$$\left.\begin{aligned}X&=-\frac{dV}{dx}=\frac{dQ}{dx}-4\pi(\alpha)\\Y&=-\frac{dV}{dy}=\frac{dQ}{dy}-4\pi(\beta)\\Z&=-\frac{dV}{dz}=\frac{dQ}{dz}-4\pi(\gamma)\end{aligned}\right\}\quad\ldots\ldots\ldots\quad(VI.)$$

The resultant of the partial components, $-4\pi(\alpha)$, $-4\pi(\beta)$, $-4\pi(\gamma)$, is a force equal to $4\pi(i)$ acting in a direction contrary to that of magnetization, and this, compounded with the resultant of

$$\frac{dQ}{dx},\ \frac{dQ}{dy},\ \frac{dQ}{dz},$$

which depends solely on the edges of the shells, gives the total resultant force at the internal point. We thus see precisely how the statements made at the commencement of § 76. are fulfilled.

Cor. 3. It is obvious, by the preceding investigation, that

$$\frac{dQ}{dx},\ \frac{dQ}{dy},\ \frac{dQ}{dz}$$

are the components of the force at a point in an infinitely small crevass perpendicular to the lines of magnetization at x, y, z.

77. An analytical demonstration of these expressions may be obtained by a partial

integration of the general expression for the potential in the case of a lamellar distribution, in the following manner:—

In equation (5) of § 55, which, as was remarked in the foot-note, expresses the potential for any point, whether internal or external, let $\frac{d\phi}{dx}$, $\frac{d\phi}{dy}$, and $\frac{d\phi}{dz}$ be substituted in place of *il*, *im*, and *in* respectively; and, for the sake of brevity, let

$$\{(\xi-x)^2+(\eta-y)^2+(\zeta-z)^2\}^{\frac{1}{2}}$$

be denoted by Δ: then observing that $\frac{\xi-x}{\Delta^3}=\frac{d\frac{1}{\Delta}}{dx}$, and so for the similar terms; we have

$$V=\iiint\left(\frac{d\phi}{dx}\frac{d\frac{1}{\Delta}}{dx}+\frac{d\phi}{dy}\frac{d\frac{1}{\Delta}}{dy}+\frac{d\phi}{dz}\frac{d\frac{1}{\Delta}}{dz}\right)dxdydz. \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

Dividing the second member into three terms, integrating the first by parts commencing with the factor $\frac{d\phi}{dx}\,dx$, and so for the other terms; we obtain

$$V=\left[\iint\phi\left(\frac{d\frac{1}{\Delta}}{dx}dydz+\frac{d\frac{1}{\Delta}}{dy}dzdx+\frac{d\frac{1}{\Delta}}{dz}dxdy\right)\right]-\iiint\phi\left(\frac{d^2\frac{1}{\Delta}}{dx^2}+\frac{d^2\frac{1}{\Delta}}{dy^2}+\frac{d^2\frac{1}{\Delta}}{dz^2}\right)dxdydz, \quad . \quad . \quad (b)$$

where the brackets which inclose the double integral denote that it has reference to the surface of the body. Now, for any set of values of x, y, z, for which $\frac{1}{\Delta}$ is finite, we have, as is well known,

$$\frac{d^2\frac{1}{\Delta}}{dx^2}+\frac{d^2\frac{1}{\Delta}}{dy^2}+\frac{d^2\frac{1}{\Delta}}{dx^2}=0; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (c)$$

and consequently, if the point ξ, η, ζ is not in the space included by the triple integral in the expression for V, each element of this integral, and therefore also the whole, vanishes. In the contrary case, the simultaneous values $x=\xi$, $y=\eta$, and $z=\zeta$ will be included in the limits of integration, and, as these values make $\frac{1}{\Delta}$ infinitely great, the equation (c) will fail for one element of the integral, although it still holds for all elements corresponding to points at a finite distance from (ξ, η, ζ). Hence, if (ϕ) denote the value assumed by the function ϕ at this point, we have

$$\iiint\phi\left(\frac{d^2\frac{1}{\Delta}}{dx^2}+\frac{d^2\frac{1}{\Delta}}{dy^2}+\frac{d^2\frac{1}{\Delta}}{dz^2}\right)dxdydz=(\phi)\iiint\left(\frac{d^2\frac{1}{\Delta}}{dx^2}+\frac{d^2\frac{1}{\Delta}}{dy^2}+\frac{d^2\frac{1}{\Delta}}{dx^2}\right)dxdydz,$$

where the limits of integration may correspond to any surface whatever which completely surrounds the point (ξ, η, ζ). Now it is easily proved (as is well known) that the value of

$$\iiint\left(\frac{d^2\frac{1}{\Delta}}{dx^2}+\frac{d^2\frac{1}{\Delta}}{dy^2}+\frac{d^2\frac{1}{\Delta}}{dz^2}\right)dxdydz$$

is -4π, when (ξ, η, ζ) is included in the limits of integration; and therefore the value of the triple integral, in the expression for V, is $-4\pi(\varphi)$. Hence, according as the point (ξ, η, ζ) is external or internal with reference to the magnet, the potential at it is given by the expressions

$$\left.\begin{aligned} &(1.)\quad V=\left[\iint\varphi.\left(\frac{d\frac{1}{\Delta}}{dx}dydz+\frac{d\frac{1}{\Delta}}{dy}dzdx+\frac{d\frac{1}{\Delta}}{dz}dxdy\right)\right] \\ \text{or}\quad &(2.)^{*}\ V=\left[\iint\varphi.\left(\frac{d\frac{1}{\Delta}}{dx}dydz+\frac{d\frac{1}{\Delta}}{dy}dzdx+\frac{d\frac{1}{\Delta}}{dz}dxdy\right)+4\pi(\varphi)\right] \end{aligned}\right\} \quad \ldots\ldots \quad \text{(VII.)}$$

These agree with the expressions obtained above in § 76; the same double integral with reference to the surface being here expressed symmetrically by means of rectangular coordinates.

78. The value of φ at any point in the surface of the magnet, which, as appears from the preceding investigations, is all that is necessary for determining the potential due to a lamellar magnet at any point not contained in the magnetized substance, may, according to well-known principles, be determined by integration, if the tangential component of the magnetization at every point of the magnet infinitely near its surface be given. It appears therefore that, if it be known that a magnet is lamellarly magnetized throughout its interior, it is sufficient to have given the tangential component of its magnetization at every point infinitely near the surface or to have enough of data for determining it, without any further specification regarding the interior distribution than that it is lamellar, to enable us to determine completely its external magnetic action. This conclusion is analogous to a conclusion which may be drawn, for the case of a solenoidal distribution, from the expression obtained in § 51, for the potential of a magnet of any kind. For, from this expression, we have, according to § 74, the following in the case of a solenoidal distribution :—

$$V=\left[\iint\frac{(l\alpha+m\beta+n\gamma)dS}{\Delta}\right] \quad \ldots\ldots\ldots \quad \text{(VIII.)};$$

from which we conclude, that without farther data regarding the interior distribution than that it is solenoidal, it is sufficient to have given the normal component of the magnetization at every point infinitely near the surface to enable us to determine the external magnetic action. Yet, although analogous conclusions are thus drawn from these two formulæ, the formulæ themselves are not analogous, as the former (that of § 51) is applicable to all distributions, whether solenoidal or not, and shows precisely how the resultant magnetic action will in general depend on the interior distribution besides the normal magnetization near the surface, according to the deviation from being solenoidal which it presents; while the formulæ of § 76. merely expresses a fact with reference to lamellar distributions, and being only applicable to lamellar distributions, do not indicate the effect of a deviation from being lamellar, in a distribution of a general form. Certain considerations regarding the comparison between common magnets and electro-magnets, suggested by AMPÈRE's theorem that the magnetic action of a closed galvanic circuit is the same as that of a "magnetic shell" (as defined in § 67.) of any form having its edge coincident with the circuit, led me to a synthetical investigation of a distribution of galvanism through the interior and at the surface of a magnet magnetized in any arbitrary manner, from which I deduced formulæ, for the resultant force at any external or internal point, giving the desired indication regarding effect of a deviation from being lamellar, on expressions which, for lamellar distributions, depend solely on the tangential component of magnetization at points infinitely near the surface. These galvanic elements throughout the body, from the action of which the resultant force at any external point is compounded, produce effects which are not separately expressible by means of a potential, and therefore, although of course when the three components X, Y, Z of the total resultant force at any point (x, y, z) have been obtained, they will be found to be such that $Xdx+Ydy+Zdz$ is a complete differential, the separate infinitely small elements of which these forces are compounded by integration with reference to the elements of the magnet, do not separately satisfy such a condition. Hence the investigation does not lead to an expression for the potential; but by means of it the following expressions for the three components of the force at any external point, or on a point within any infinitely small crevass perpendicular to the lines of magnetization, have been obtained*:—

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* It may be proved that the force derived from a potential having the same expression (VII.) (1.) as for external points, is, for any internal point, the force at a point within an infinitely small crevass perpendicular to the lines of magnetization; as it is easily shown that the differential coefficients of $4\pi(\varphi)$ are the rectangular components of the force at such a point due to the free contrary polarities on the two sides of the crevass.

$$\left.\begin{aligned}
X&=\iiint dxdydz\left\{\frac{\eta-y}{\Delta^3}\left(\frac{d\alpha}{dy}-\frac{d\beta}{dx}\right)-\frac{\zeta-z}{\Delta^3}\left(\frac{d\gamma}{dx}-\frac{d\alpha}{dz}\right)\right\}-\left[\iint\left\{\frac{\eta-y}{\Delta^3}(m\alpha-l\beta)-\frac{\zeta-z}{\Delta^3}(l\gamma-n\alpha)\right\}dS\right]\\
Y&=\iiint dxdydz\left\{\frac{\zeta-z}{\Delta^3}\left(\frac{d\beta}{dz}-\frac{d\gamma}{dy}\right)-\frac{\xi-x}{\Delta^3}\left(\frac{d\alpha}{dy}-\frac{d\beta}{dx}\right)\right\}-\left[\iint\left\{\frac{\zeta-z}{\Delta^3}(n\beta-m\gamma)-\frac{\xi-x}{\Delta^3}(m\alpha-l\beta)\right\}dS\right]\\
Z&=\iiint dxdydz\left\{\frac{\xi-x}{\Delta^3}\left(\frac{d\gamma}{dx}-\frac{d\alpha}{dz}\right)-\frac{\eta-y}{\Delta^3}\left(\frac{d\beta}{dz}-\frac{d\gamma}{dy}\right)\right\}-\left[\iint\left\{\frac{\xi-x}{\Delta^3}(l\gamma-n\alpha)-\frac{\eta-y}{\Delta^3}(n\beta-m\gamma)\right\}dS\right]
\end{aligned}\right\}$$

The investigation by which I originally obtained these expressions is, with reference to galvanism, precisely analogous to the investigation in § 42. with reference to imaginary magnetic matter. It cannot be given without explanations regarding the elements of electro-magnetism which would exceed the limits of the present communication; but when I had once discovered the formulæ I had no difficulty in working out the subjoined analytical demonstration of them for the case of an external point, which is precisely analogous to POISSON's original investigation (shown in § 56. of this paper) of the formula of § 51.

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* The expression $Xdx+Ydy+Zdz$ will not be a complete differential for internal points, unless the distribution of magnetism be lamellar, since, for any internal point, X, Y, Z differ from the rectangular components of the resultant force, as defined in § 48, by the quantities $4\pi\alpha$, $4\pi\beta$, $4\pi\gamma$, respectively, and since (§ 52) the resultant force, for all points, whether internal or external, is derivable from a potential.

79. Equations (3) and (4) of §§ 51. and 52, lead to expressions for the components of the resultant force at any point in the neighbourhood of a magnet. Taking only one of them, (since the three expressions are symmetrical) that for X for instance, we have

$$X=-\frac{d}{d\xi}\iiint dxdydz\left\{\alpha\frac{d\frac{1}{\Delta}}{dx}+\beta\frac{d\frac{1}{\Delta}}{dy}+\gamma\frac{d\frac{1}{\Delta}}{dz}\right\}.$$

Now if the factor of $dxdydz$ in the second member of this equation be differentiated with reference to ξ, an expression is obtained which does not become infinitely great for any values of x, y, z included within the limits of integration, since the point (ξ, η, ζ) is considered to be external in the present investigation. Hence the differentiation with reference to ξ may be performed under the integral sign; and, since

$$\frac{d\frac{1}{\Delta}}{d\xi}=-\frac{d\frac{1}{\Delta}}{dx},$$

we thus obtain

$$X=\iiint dxdydz\left\{\alpha\frac{d^2\frac{1}{\Delta}}{dx^2}+\beta\frac{d^2\frac{1}{\Delta}}{dy^2}+\gamma\frac{d^2\frac{1}{\Delta}}{dz^2}\right\}^*.$$

Now, for all points included within the limits of integration, we have, from LAPLACE's well-known equation,

$$\frac{d^2\frac{1}{\Delta}}{dx^2}=-\left(\frac{d^2\frac{1}{\Delta}}{dy^2}+\frac{d^2\frac{1}{\Delta}}{dz^2}\right),$$

and therefore

$$X=\iiint dxdydz\left\{-\alpha\left(\frac{d^2\frac{1}{\Delta}}{dy^2}+\frac{d^2\frac{1}{\Delta}}{dz^2}\right)+\beta\frac{d^2\frac{1}{\Delta}}{dxdy}+\gamma\frac{d^2\frac{1}{\Delta}}{dxdz}\right\}.$$

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* If the point (ξ, η, ζ) be either within the magnet, or infinitely near it, the factor of $dxdydz$ in this integral is infinitely great for values of (x, y, z) included within the limits of integration; and it may be demonstrated that the value of a part of the integral corresponding to any infinitely small portion of the magnet infinitely near the point (ξ, η, ζ) is in general finite, and that it depends on the form of this portion, on its position with reference to the line of magnetization through (ξ, η, ζ), and on the proportions of the distances of its different parts from this point. It follows that if the point ξ, η, ζ be internal, and if a portion of the magnet round it be omitted from the integral, the value of the integral will be affected by the form of the omitted portion, however small its dimensions may be, and consequently the complete integral has no determinate value if the point (ξ, η, ζ) be internal. Hence, although as we have seen above (§§ 51, 51.),

$$-\frac{d}{d\xi}\iiint dxdydz\left\{\alpha\frac{d\frac{1}{\Delta}}{dx}+\beta\frac{d\frac{1}{\Delta}}{dy}+\gamma\frac{d\frac{1}{\Delta}}{dz}\right\}$$

has in all cases a determinate value, which, by the definition (§ 48.), is called the component parallel to OX of the resultant force at (ξ, η, ζ), the expression

$$-\iiint dxdydz\frac{d}{d\xi}\left\{\alpha\frac{d\frac{1}{\Delta}}{dx}+\beta\frac{d\frac{1}{\Delta}}{dy}+\gamma\frac{d\frac{1}{\Delta}}{dz}\right\}$$

has no meaning when (ξ, η, ζ) is in the substance of the magnet.

Dividing the second member into four terms, and applying an obvious process of integration by parts, we deduce

$$\mathrm{X}=\Bigg[\iint\left\{-\alpha\frac{d\frac{1}{\Delta}}{dy}dxdz-\alpha\frac{d\frac{1}{\Delta}}{dz}dxdy+\beta\frac{d\frac{1}{\Delta}}{dy}dydz+\gamma\frac{d\frac{1}{\Delta}}{dz}dydz\right\}$$

$$+\iiint dxdydz\left\{\frac{d\alpha}{dy}\frac{d\frac{1}{\Delta}}{dy}+\frac{d\alpha}{dz}\frac{d\frac{1}{\Delta}}{dz}-\frac{d\beta}{dx}\frac{d\frac{1}{\Delta}}{dy}-\frac{d\gamma}{dz}\frac{d\frac{1}{\Delta}}{dz}\right\}\Bigg].$$

Modifying the double integral by assuming, in its different terms,

$$dydz=ld\mathrm{S}\,;\quad dzdx=md\mathrm{S}\,;\quad dxdy=nd\mathrm{S},$$

and altering the order of all the terms, we obtain

$$\mathrm{X}=\iiint dxdydz\left\{\frac{d\frac{1}{\Delta}}{dy}\left(\frac{d\alpha}{dy}-\frac{d\beta}{dx}\right)-\frac{d\frac{1}{\Delta}}{dz}\left(\frac{d\gamma}{dx}-\frac{d\alpha}{dz}\right)\right\}-\left[\iint\left\{\frac{d\frac{1}{\Delta}}{dy}(m\alpha-l\beta)-\frac{d\frac{1}{\Delta}}{dz}(l\gamma-n\alpha)\right\}d\mathrm{S}\right]$$

This expression, when the indicated differentiations are actually performed upon $\frac{1}{\Delta}$, becomes identical with the expression for X at the end of § 78, and the formulæ which it was required to prove are therefore established.

80. The triple integrals in these expressions vanish in the case of a lamellar distribution, in virtue of the equations (III.) of §§ 75 ; and we have simply

$$\left.\begin{aligned}\mathrm{X}&=-\left[\iint\left\{\frac{d\frac{1}{\Delta}}{dy}(m\alpha-\ l\beta)-\frac{d\frac{1}{\Delta}}{dz}(\ l\gamma-\ n\alpha)\right\}d\mathrm{S}\right]\\ \mathrm{Y}&=-\left[\iint\left\{\frac{d\frac{1}{\Delta}}{dz}(n\beta-m\gamma)-\frac{d\frac{1}{\Delta}}{dx}(m\alpha-\ l\beta)\right\}d\mathrm{S}\right]\\ \mathrm{Z}&=-\left[\iint\left\{\frac{d\frac{1}{\Delta}}{dx}(\ l\gamma-\ n\alpha)-\frac{d\frac{1}{\Delta}}{dy}(n\beta-m\gamma)\right\}d\mathrm{S}\right]\end{aligned}\right\}\quad\ldots\ldots\quad(\mathrm{X.}).$$

To interpret these expressions, let us assume, for brevity,

$$\mathrm{U}=n\beta-m\gamma\,;\ \mathrm{V}=l\gamma-n\alpha\,;\ \mathrm{W}=m\alpha-l\beta\quad\ldots\ldots\ldots\quad(\mathrm{XI.}).$$

From these we deduce

$$\left.\begin{aligned}m\mathrm{W}-n\mathrm{V}&=\alpha-l\ (l\alpha+m\beta+n\gamma)=\alpha_{\prime}\\ n\mathrm{U}\ -l\mathrm{W}&=\beta-m(l\alpha+m\beta+n\gamma)=\beta_{\prime}\\ l\mathrm{V}\ -m\mathrm{U}&=\gamma-n\ (l\alpha+m\beta+n\gamma)=\gamma_{\prime}\end{aligned}\right\}\quad\ldots\ldots\ldots\quad(\mathrm{XII.})\,;$$

where $\alpha_{\prime}$, $\beta_{\prime}$, $\gamma_{\prime}$ denote the rectangular components of the tangential component of the magnetization at a point infinitely near the surface. Conversely, from these equations we deduce

$$\mathrm{U}=n\beta_{\prime}-m\gamma_{\prime}\,;\ \mathrm{V}=l\gamma_{\prime}-n\alpha_{\prime}\,;\ \mathrm{W}=m\alpha_{\prime}-l\beta_{\prime}\ \ldots\ldots\ldots\quad(\mathrm{XIII.}).$$

Now the direct data required for obtaining the values of X, Y, and Z, by means of formulæ (X.), are simply the values of U, V, W at all points of its surface. Equations (XII.) show that with these data the values of $\alpha_{\prime}$, $\beta_{\prime}$, $\gamma_{\prime}$ may be calculated; and again, equations show conversely that if $\alpha_{\prime}$, $\beta_{\prime}$, $\gamma_{\prime}$ be given the required data for the problem may be immediately deduced. We infer that the necessary and sufficient data for determining the resultant force of a lamellar magnet, at any external point, by means of formulæ (X.), are equivalent to a specification of the direction and magnitude of the tangential component of the intensity of magnetization at every point infinitely near the surface of the magnet; and we conclude, as we did in § 78 from a very different process of reasoning, that besides these data, nothing but that it is lamellar throughout need be known of the interior distribution.

81. The close analogy which exists between solenoidal and lamellar distributions of magnetism having led me to the new formulæ which have just been given, it occurred to me that a formula (or formulæ, if it were necessary here to separate the cases of internal and external points,) for solenoidal distributions analogous to the formulæ (VII.) of §§ 77 for lamellar distributions might be discovered. Taking an analytical view of the problem (the synthetical view, although itself much more obvious, not showing any very obvious way of arriving at a formula of the desired kind), I observed that the formula $\iint \frac{\phi \,.\, \cos \theta dS}{\Delta^2}$ is deduced from the general expression for the potential, by a partial integration performed upon factors involving α, β, γ, and depending on the integrability of the function $\alpha dx+\beta dy+\gamma dz$, ensured by the equations

$$\frac{d\beta}{dz}-\frac{d\gamma}{dy}=0, \quad \frac{d\gamma}{dx}-\frac{d\alpha}{dz}=0, \quad \frac{d\alpha}{dy}-\frac{d\beta}{dx}=0,$$

for a lamellar distribution; and I endeavoured to find a corresponding mode of treatment for solenoidal distributions, to consist of a partial integration, commencing still with factors involving α, β, γ, but depending now upon the single equation

$$\frac{d\alpha}{dx}+\frac{d\beta}{dy}+\frac{d\gamma}{dz}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a),$$

instead of three equations required in the former process. After some fruitless attempts to connect this equation with the integrability of some function of two independent variables, I fell upon the following investigation, which exactly answered my expectations.

82. In virtue of the preceding equation (a), we may assume

$$\alpha=\frac{dH}{dy}-\frac{dG}{dz}, \quad \beta=\frac{dF}{dz}-\frac{dH}{dx}, \quad \gamma=\frac{dG}{dx}-\frac{dF}{dy} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (XIV.),$$

where F, G, H are three functions to a certain extent arbitrary, which, as I have since found, have for their most general expressions

$$\left.\begin{aligned} F&=\iint dydz\left(\frac{d\beta}{dy}-\frac{d\gamma}{dz}\right)+\frac{d\psi}{dx} \\ G&=\iint dzdx\left(\frac{d\gamma}{dz}-\frac{d\alpha}{dx}\right)+\frac{d\psi}{dy} \\ H&=\iint dxdy\left(\frac{d\alpha}{dx}-\frac{d\beta}{dy}\right)+\frac{d\psi}{dz} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (XV.)$$

where ψ denotes an absolutely arbitrary function; and the indicated integrations are indefinite, with the arbitraries which they introduce subject to the equations (XIV.).

The demonstration of these equations follows immediately from the results obtained by differentiating the three equations (XIV.) with reference to x, y and z respectively. The simplest final forms for F, G and H are the following, which are deduced from the preceding by integration:—

$$\left.\begin{aligned} F&=\int(\beta dz-\gamma dy)+\frac{d\psi}{dx}\\ G&=\int(\gamma dx-\alpha dz)+\frac{d\psi}{dy}\\ H&=\int(\alpha dy-\beta dx)+\frac{d\psi}{dz}\end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad \text{(XVI.)}$$

Making substitutions according to the formulæ (XIV.) for α, β, γ in the general expression for the potential, we have

$$V=\iiint dxdydz\left\{\left(\frac{dH}{dy}-\frac{dG}{dz}\right)\frac{d\frac{1}{\Delta}}{dx}+\left(\frac{dF}{dz}-\frac{dH}{dx}\right)\frac{d\frac{1}{\Delta}}{dy}+\left(\frac{dG}{dx}-\frac{dF}{dy}\right)\frac{d\frac{1}{\Delta}}{dz}\right\}.$$

Dividing the second member into six terms, and integrating each by parts, commencing upon the factors such as $\frac{dH}{dy}dy$, we obtain an expression, with a triple integral involving six terms which destroy one another two and two because of properties such as

$$\frac{d}{dy}\frac{d\frac{1}{\Delta}}{dx}=\frac{d}{dx}\frac{d\frac{1}{\Delta}}{dy};$$

and besides, a double integral, which may be reduced in the usual manner to a form involving dS, an element of the surface. We thus obtain, finally,

$$V=\left[\iint\left\{(mH-nG)\frac{d\frac{1}{\Delta}}{dx}+(nF-lH)\frac{d\frac{1}{\Delta}}{dy}+(lG-mF)\frac{d\frac{1}{\Delta}}{dz}\right\}dS\right] \quad . \; . \; . \quad \text{(XVII.)}$$

83. The second member of this equation expresses the potential of a certain distribution of magnetism in an infinitely thin sheet coinciding with the surface of the body; the total magnetic moment of the magnetism in the area dS being

$$\{(mH-nG)^2+(nF-lH)^2+(lG-mF)^2\}^{\frac{1}{2}}dS,$$

and its direction cosines proportional to

$$mH-nG, \quad nF-lH, \quad lG-mF.$$

Now we have identically,

$$l(mH-nG)+m(nF-lH)+n(lG-mF)=0;$$

and hence the direction of this imaginary magnetization at every point of the surface is perpendicular to the normal. It follows that we have found a distribution of tangential magnetism in an infinitely thin sheet coinciding with the bounding surface which produces the same potential at any point, internal or external, as the given solenoidal magnet.

84. The same general conclusion may be arrived at synthetically in a very obvious manner, by taking into account the property of a solenoid stated in § 71, according to which it appears that any two solenoids of equal strength, with the same ends, produce the same force at any point whether in the magnetized substance of either, or not. For it follows from this, that when a magnet is divisible into solenoids with their ends on its surface, by joining the two ends of each solenoid by any arbitrary curve on this surface and laying a solenoid of equal strength along this curve, we obtain a series of solenoids, constituting by their superposition, a tangential distribution of magnetism in an infinitely thin sheet coinciding with the bounding surface, which produces the same resultant force at any internal or external point as the given magnet. It is not, however, easy to deduce from this synthesis, a formula involving the requisite arbitrary functions to express a superficial distribution satisfying the existing conditions in the most general manner. The analytical investigation given above, supplies, in reality, a complete solution of this problem.

It may be remarked that the sole condition which F, G and H, considered as functions of the coordinates, x, y, z, of some point in the surface of the magnet, and therefore functions of two independent variables, must satisfy in order that (XVII.) may express correctly the potential at any point—

$$l\left(\frac{d\mathrm{H}}{dy}-\frac{d\mathrm{G}}{dz}\right)+m\left(\frac{d\mathrm{F}}{dz}-\frac{d\mathrm{H}}{dx}\right)+n\left(\frac{d\mathrm{G}}{dx}-\frac{d\mathrm{F}}{dy}\right)=l\alpha+m\beta+n\gamma, \quad . \quad . \quad \text{(XVIII.)},$$

x, y and z of course being supposed to satisfy the equation to the surface; and it may be proved, by a demonstration independent of the investigation which has been given, that the second member of (XVII.) has the same value for any functions F, G, H whatever, which are subject to this relation.

END OF CHAPTER V.

XII. *Magnetic Survey of the Eastern Archipelago. By Captain* C. M. Elliot, *of the Madras Engineers. Communicated by Lieut.-Col.* Sabine, *V.P. Treas. R.S. &c.*

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In accordance with instructions received from the Honourable the Court of Directors of the East India Company, and at the recommendation of the Royal Society, I commenced, in the month of January 1846, the Magnetic Survey of the Eastern Archipelago.

As, in the prosecution of this work, I was left entirely to my own discretion, I may be permitted to state, that the principal object of the Survey appeared to me to consist in determining the position of certain magnetic lines which were included within the space I had to traverse; such, for instance, as the line of no dip, and of the maximum horizontal component of the force; from these, to determine the line of minimum intensity; and finally, the line of no variation and its direction. The determination of these lines I considered to be the principal object; but in addition, I was anxious to take hourly observations of the elements of the earth's magnetism, in order to ascertain whether the changes of declination and of magnetic intensity were uniformly similar over so large an area. The fixed stations for this latter purpose were sixteen in number, and the time employed at each station varied from a few days to several months. The fixed stations were spread over an area of 28° of latitude and of 45° of longitude, viz. from 16° latitude north to 12° latitude south, and from 80° to 125° longitude east. With reference to the line of no dip, which in this part of the globe coincides very nearly with the line of minimum intensity, I may state, that of the sixteen stations, nine were to the south, three to the north, and four in its immediate vicinity. With reference to geographical position, four were in the islands adjacent to Singapore; one in Borneo; one in the island of Java; two in Sumatra; one in the island of Mindanao; one in Celebes; one at the Cocos or Keeling Islands, which was the most southern station to which I could venture; one at Penang, and one in its immediate vicinity; one at Nicobar, in the bay of Bengal; one at Moulmein, which was my most northern; and, finally, one at Madras, which was my most western station. The Survey is however incomplete, as it would have been desirable to extend it considerably more to the eastward, in order to lay down with greater certainty the continuation, of the line of no dip and of the line of minimum intensity; and likewise I should have wished to proceed more to the northward, to ascertain with greater exactitude, at what distance north of the line of minimum intensity, the magnetic declination changes those periods of extreme easterly and extreme westerly variation, by which it is characterized in the southern magnetic hemisphere.

In January 1846 I started from Singapore, and after visiting some islands in the vicinity, which I was enabled to do through the kindness of Colonel BUTTERWORTH, C.B., the Governor of the Straits, I proceeded, in May 1846, to Borneo, where I remained some time with my friend Sir JAMES BROOKE, K.C.B., and making Sarāwak my head-quarters, I took observations at several of the Dutch settlements on the western coast. From Borneo I proceeded to Java, where I passed ten months, and went on to Sumatra in August 1847; but from severe illness brought on through over-exertion in the magnetic survey of part of that island, I was forced to return to Singapore for medical advice in February 1848. At Singapore I remained for some weeks; during which time I was able to take a considerable number of observations of dip and of horizontal intensity; and early in April 1848 I again left Singapore, and visited successively, Pulo Labooan, Sambooanga in the island of Mindanao, and Keemah in the Celebes. From Keemah I proceeded to the Keeling or Cocos Islands, and from the Cocos returned to Batavia, whence I was on the point of proceeding to the eastward and to New Guinea; when I received instructions which induced me to return to Madras, in consequence of having unfortunately very much exceeded the time allotted to me; and thus an end was put to the Survey, which the liberal patronage of the Court of Directors of the East India Company had enabled me to undertake, and which I had hoped to render complete. I returned to Singapore at the close of the year 1848; and here let me gratefully acknowledge, the kind and hospitable treatment I received everywhere from the Dutch authorities. No restrictions were placed on my movements; I was allowed to proceed wherever I chose, and I rejoice at the opportunity thus afforded me of recording my sense of their uniform liberality; nor can I omit mentioning my obligations to His Excellency Baron ROCHUSSEN, the Governor-General of the Dutch Possessions in the East; to His Excellency General VAN DER WEYCK, the Commander-in-Chief in Java, and to Captain SMITZ, the Hydrographer, who rendered me very great service in his superintendence of the magnetic observatory during my occasional absence from Batavia.

Quitting Singapore for the last time, I stopped at Penang on my way to Nicobar Island, which I was anxious to visit from its being in the immediate vicinity of the line of no dip and of minimum intensity.

I then visited Moulmein, and from Moulmein proceeded to Madras, which I reached in June 1849, from which time till the month of October I was employed there in taking a complete set of absolute determinations, and of hourly magnetic observations, in which latter duty I received the kind aid of Captain JACOB, the Honourable East India Company's Astronomer. Madras was my last station, and I there concluded the Survey. Having then to reduce and bring into shape an enormous mass of work, it occurred to me that the difficulties I should encounter in publishing in India a system of observation, combining the details of a fixed observatory with those of a magnetic survey, would be very great. I therefore applied for furlough, and came to England for the sole purpose of publishing my observations, after reducing them into as condensed a form as was consistent with perspicuity.

Since my arrival in England I have been in constant communication with Colonel

Sabine, R.A., to whose zealous superintendence and advice I am indebted, on almost every point connected with the reduction of the observations: I have likewise to express my obligations to Dr. Lloyd for his advice and for many acts of kindness; from their joint Report on the Magnetic Isoclinal and Isodynamic Lines in the British Islands, I have laid down, in a manner similar to the method there adopted, the different magnetic lines on the Chart of the Eastern Seas; while to the "Magnetical Instructions for the use of Portable Instruments," drawn up by Captain Riddell, R.A., I am indebted for the abstracts and forms in which the different instruments are registered.

I do not therefore pretend to any originality in my plan; and the only merit I lay claim to is, that these observations, taken under many difficulties, were made with the earnest desire to do credit to the Royal Society, who recommended the Survey, and to the East India Company, whose munificence enabled me to undertake it.

The Survey consisting; first, of the observation of the differential changes of magnetic and meteorological phenomena at sixteen stations; secondly, of absolute determinations of dip, intensity, and variation in Java, Sumatra, Borneo and other islands of the Archipelago; thirdly, of magnetic and meteorological observations at sea,—it will perhaps be best to treat of each separately, and I shall therefore commence with the observatories.

The following Table contains the names of the different stations at which observatories were established, commencing with the most northerly. The first column contains the stations; the second and third, the latitudes and longitudes; the fourth and fifth, the materials with which the observatories were constructed; the sixth, the nature of the soil; the seventh, the number of days of observation; the eighth, the year and month; and the ninth, the place of observation.

Station.	Latitude.	Longitude.	Materials with which the Observatories were constructed.		Nature of soil.	No. of days observation.	Year and Month.	Places of observation.
			Roof.	Walls.				
Moulmein ...	16° 26′ 49″ N.	97° 45′ 30″ E.	Double thickness of canvas.	Cotton-cloth ...	Clay	7	April 1849	Near Captain Berdmore's house.
Madras	13 04 09	80 16 30	Cotton-cloth ...	Cotton-cloth ...	Clay and sand.	34	Aug. and Sept. 1849 .	At the fixed Magnetic Observatory.
Nicobar	9 10 12	92 48 23	Double thickness of canvas.	Cotton-cloth ...	Coral and sand.	5	February 1849.........	Near the sea-shore.
Sambooanga .	6 54 20	122 13 45	Double thickness of canvas.	Canvas...........	Clay and sand.	6	May 1848	Near the sea-shore.
Penang	5 25 36	100 24 30	Double thickness of canvas.	Folds of cotton-cloth.	Clay and sand.	5	January 1849	Near the sea-shore.
Pulo Dinding	4 12 47	100 32 52	Double thickness of canvas.	Folds of cotton-cloth.	Clay.........	3	January 1849	Near the sea-shore.
Sarāwak	1 33 54	110 29 00	Thatched with leaves of Neepa.	Leaves of the Neepa palm.	Clay.........	72	June, July and August 1846.	Near Sir J. Brooke's house.
Keemah, Celebes.	1 21 55	125 07 59	Canvas...........	Canvas...........	Clay.........	10	June 1848	In the village, not far from the shore.
Pulo Peesang	1 27 53	103 19 15	Canvas...........	Canvas...........	Clay and sand.	5	January 1846	Close to the sea-shore.
Singapore ...	1 18 32	103 56 30	Thatched with leaves of Neepa.	Wood and sun-burnt bricks.	Sand upon blue clay.	30	Nov. and Dec. 1848 .	At the fixed Magnetic Observatory.
Carimon......	0 59 22	103 27 00	Canvas...........	Canvas...........	Sand	6	January 1846	Close to the sea-shore.
Pulo Booāya .	0 09 09	104 21 00	Canvas...........	Canvas...........	Sand	4	February 1846.........	On the sea-shore.
Padang, Sumātra.	0 58 58 S.	100 31 15	Double thickness of canvas.	Canvas...........	Ferruginous sand.	78	Oct., Nov., Dec., 1847 and Jan. 1848.	Near the sea-shore.
Batavia	6 09 52	106 58 00	Thatched with leaves of Neepa.	Thick bamboo matting.	Clay.........	199	From Nov. 1846 to July 1847.	In the midst of a vast plain of rice-fields.
Cocos or Keeling Islands.	12 05 38	96 50 30	Double thickness of canvas.	Cocoa-nut leaves	Fragments of coral.	27	August and September 1848.	Close to the sea-shore.

The instruments in use at the observatories were the following:—

No. I. Portable Declination Magnetometer, showing changes of declination or of variation.

No. II. Induction Inclinometer, showing likewise changes of declination.

No. III. JONES' new Declinometer, in use during the latter period of the Survey, showing likewise changes of declination.

Nos. IV. and V. Portable Bifilar Magnetometer with Thermometer, showing changes of horizontal intensity.

Nos. VI. and VII. Barometer and Thermometer; NEWMAN'S Standard Barometer was in use during the first part of the Survey; and latterly, a Portable Instrument by CARY.

Nos. VIII. and IX. Dry and Wet-bulb Thermometers.

No. X. Standard Thermometer.

Nos. XI. and XII. Maximum and Minimum Thermometers.

Observatories, Position of the Instruments, &c.

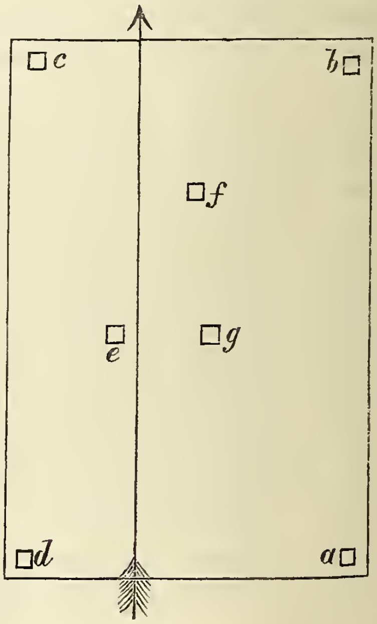
As all the observatories were constructed upon the same principle, it will not be necessary to give the positions and adjustments of the instruments at more than two of the stations; the details of the rest being precisely of a similar nature; for this purpose the position of the instruments, their adjustments and the dimensions of the observatories on Direction Island, Cocos; and at Batavia, are given.

Observatory on Direction Island, Cocos or Keeling Islands.

The observations at the Cocos or Keeling Islands were made on Direction Island, with the usual magnetic and meteorological instruments. The soil on Direction Island consists of a few inches of vegetable soil, and of several feet in depth of fragments of coral. The observatory tent was pitched in the midst of a thick plantation of cocoa-nut trees about 8 feet above the level of low-water mark, and about 50 yards from the sea.

Dimensions of the tent 19 × 13 feet. Tent consisted of a double lining of canvas, and the walls of cocoa-nut leaves.

a. Declinometer No. I.
b. Declinometer No. II.
c. Declinometer No. III.
d. Bifilar and Thermometer.
e. Barometer and Thermometer.
f. Dry and Wet Bulb.
g. Standard Thermometer.



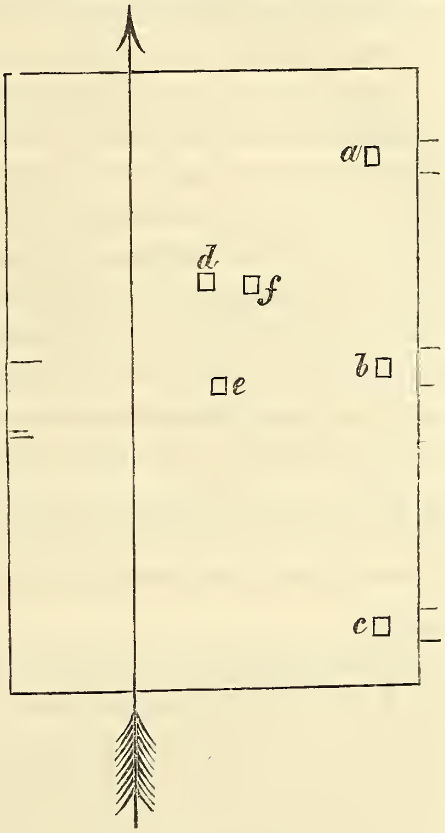
The magnetic instruments were placed at the four corners as remote from one another as the dimensions of the tent would permit. The Standard Thermometer was attached to one of the poles of the tent. The Barometer fixed to a detached post firmly imbedded in the ground. The Dry and Wet-Bulb Thermometers were placed on a small table, 5 feet above the ground.

Observatory at Batavia.

The dimensions of this building were 42×28 feet, and almost wholly constructed of bamboo; the walls were 12 feet in height, composed of thick bamboo matting, and the roof was thatched with leaves of the Neepa palm. The soil was a very stiff clay, and the spot selected was in the midst of extensive rice-fields.

a. Bifilar Magnetometer, on a pillar constructed of sun-dried bricks, capped by a slab of granite.
b. Declinometer No. II. on a wooden stand.
c. Declinometer No. I. on a pillar of sun-dried bricks.
d. Standard Barometer with its Thermometer.
e. Dry and Wet Bulb.
f. Standard Thermometer.

The Bifilar at the N.E. angle, the scale facing the south; Declinometer No. II. at the point *b*, and Declinometer No. I. at the point *c*, both facing the east, the instruments being about 18 feet apart; the Dry and Wet Bulb on a table at *e*; the Standard Barometer attached to a post firmly imbedded in the earth at *d*; the Standard Thermometer fixed to a post at *f*.



Times of Observation.

Having during the greater part of the Survey but one assistant, I limited the observations to nineteen hours daily, viz. hourly observations from 3 A.M. to 9 P.M. To this arrangement there are exceptions; as at Sarāwak and during the first four months at Batavia, when I had three assistants; and then observations were taken hourly during the twenty-four hours. By astronomical time, therefore, the observations generally commenced at fifteen hours, and terminated at nine hours.

Order in which the Instruments will be noticed.

The instruments will be noticed in the following order:—The Declinometers, the Bifilar, the Dry and Wet-Bulb Thermometers, the Barometer, the Standard Thermometer, and the Maximum and Minimum Thermometers.

Declinometers.

There were never less than two declinometers observed at the same station, and subsequently, when Jones's declinometer was received, all three were put in adjustment and observed. At Pulo Peesang, Carimon, Pulo Booāya, Sarāwak, Batavia, Poolo Bay, Padang and Sambooanga, Nos. I. and II. were employed; at Moulmein, Nos. II. and III.; at Keemah, the Cocos, Pulo Dinding, Penang, Nicobar, and Madras, Nos. I. II. and III.; and at Singapore, in November and December 1848, not only were the three above-mentioned observed, but two in addition, viz. No. IV., a small cylindrical magnet 3 inches in length, in use for deflection in a separate building, and No. V., the large 15-inch bar in the observatory.

Declinometer No. I.—Declinometer No. I. is the Portable Declination Magnetometer described in Captain RIDDELL's work on Magnetic Instruments; the magnet is a solid cylinder 3 inches in length and suspended by a filament of untwisted silk; the former enclosed in a copper box, the latter in a glass tube. A scale being fixed above the telescope and reflected by a mirror attached to the stirrup in which the magnet is placed, the changes in the position of the magnet are shown by the mirror reflecting different portions of the ivory scale, and are read off by the telescope attached to the instrument. The mirror is immediately below the magnet and parallel to its longer axis; the scale faced the east, and increasing readings denote a movement of the north pole east. The ratio of the torsion force to the magnetic directive force, or the value of $\frac{H}{F}$, varied from ·000207 to ·000278. The value of one scale division in arc value is $a' = 3437{\cdot}75 \times \frac{l}{2r} = 1'{\cdot}00$, where $l = \frac{1}{100}$th of an inch $=$ ·01 and $r = 17{\cdot}19$ inches.

Declinometer No. II.—Declinometer No. II. is the Induction Inclinometer described at page 12 of RIDDELL's work. The magnet is of the same length as No. I., but hollow. The adjustments are precisely similar. The mirror is parallel to and immediately below the longer axis of the magnet. The value of one scale division is exactly the same as for No. I., viz. $1'$ of arc. The coefficient of torsion varied from ·000139 to ·00025, and is therefore not worth taking into account, except for large angles of deflection.

Declinometer No. III.—Declinometer No. III., or JONES's Declinometer, is precisely similar in principle to the two others; the magnet being a solid cylinder 3 inches in length. The mirror, instead of being parallel to the longer axis of the magnet, is at right angles to it, so that the scale, instead of facing the east, being to the south of the magnet, faced the north. Increasing scale readings denote a movement of the north pole east. The value of one scale division is $1'{\cdot}0036$; the coefficient of torsion ·00031.

Contents of Abstracts of Table A. *referring to the Declinometers.*

In the abstracts of Table A. are given, from page i to page xi inclusive, the oscillation, or more properly the variation of the declination* at the different stations in the Eastern Archipelago; pages ii and iii contain the mean oscillation of the declination, the range extending from the most westerly declination assumed as zero, to the most eastern position of the magnet. As increasing readings denote a movement of the north pole of the magnet eastward, the lowest number will of course be the most western position or zero, the highest number being the most eastern position. As these tables contain the mean oscillation for several months, the oscillations at those stations where observations have been taken for more than one month are given in pages iv to vii inclusive.

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* In order to obviate confusion as much as possible, I have substituted in Table A. for hourly variation the word oscillation, which is meant to express the extreme range or swing of the needle from its most western to its most eastern position: the term hourly variation has not been used in Table A., as it might be con-

In addition to the three Portable Declinometers, No. IV., a small 3-inch cylinder used as the deflected magnet in the determination of the absolute horizontal intensity, and No. V., the 15-inch observatory bar, were observed at Singapore. The oscillations of these two instruments are given at pages iv and v, reduced to minutes of angular space, and the mean results are included in the Table of Declinometer No. III. at pages ii and iii. It occurred to me constantly whilst at the observatory to note, that not only did the large magnet differ from the smaller magnets in its time of changing, but the range or oscillation was not the same; the time of change differed but slightly it is true; but it was not identically the same*. I determined therefore to use on the Survey never less than two magnets; one a solid, the other a hollow cylinder, for the changes of declination; and on my return to Singapore in 1848, I took nearly simultaneous observations of as many declination magnets as could be observed together.

On inspection of the Tables of the mean oscillation of the declination at pages ii and iii, I was struck with the dissimilarity of the times of occurrence of minimum westerly declination at the different survey stations; and as the observations were taken at all seasons of the year, it appeared to be exceedingly desirable to have some fixed observatory to refer to, to ascertain what changes might be due to geographical position and what changes to the time of the year. I have, therefore, at pages viii, ix, x and xi, given the mean hourly oscillation of the magnetic declination at the Singapore Observatory, for each season being the mean of three years; the mean of each of the months; and finally, the mean of each of the three years, showing the

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founded with the angle α, or the angle which the magnetic meridian forms with the true meridian, and which is usually called the variation of the needle; but to prevent mistakes, for the angle α, the term magnetic declination has been substituted, in accordance with the method now generally adopted.

* I attributed at the time this difference of range, and the turning points not being exactly simultaneous, to the method of suspension by filaments of silk, and the constant change to which the force of torsion was liable from the hygrometric properties of the silk. The large observatory 15-inch bar was suspended by eighteen fibres of untwisted silk; and when a fresh adjustment became necessary from the threads breaking, a brass bar was swung, in order to take the torsion out of the new suspension thread: after getting the brass bar accurately into the magnetic meridian, it would remain in the same position for several hours; but, if adjusted during the day, it would be found, after the lapse of a night, forming some angle with the magnetic meridian; thus, from some cause, hygrometric or otherwise, the plane of detorsion was no longer in the same position in which it had previously been in adjustment.

remarkable similarity of one year with another. As the sole object in giving these Singapore tables, was to determine the times of extreme easterly and westerly declination, in the southern magnetic hemisphere near the line of minimum intensity, the results of the Singapore Observatory magnet are not in this instance given in minutes of arc, but in scale divisions; one scale division being equal to $40''\cdot7$ of arc.

Table A.—Pages xii to xlvii contain the results of the declinometers at the sixteen stations in the Archipelago. The stations are given proceeding from the most northern to the most southern: the observations themselves are omitted. At the top of every double page is printed the name of the station, with its latitude and longitude; the mean astronomical time at the station; and the value of one scale division in minutes of arc, multiplied by the coefficient of torsion or $1+\frac{\text{H}}{\text{F}}$; the value of which is so trifling as not to affect the small diurnal changes of the magnet; and the zero of the month, which is the scale division of the magnet at that hour at which the absolute determination of the magnetic declination was made, usually at 9 A.M. The results of each instrument are contained in five lines; the first, the sums of the scale readings; the second, the means; the third, the diurnal changes, from the mean of the month*; the fourth, the range or oscillation of the needle, from its minimum or most western position; and the fifth, the diurnal declination.

Curves.

The curves of the declinometer are given in Plates IV., V. and VI. Part 1 of Plate IV. contains the curves of the declinometer at those stations where observations were made during the spring and summer; Part 2 of Plate IV. and Part 1 of Plate V. the winter curves; Part 2 of Plate V. the equinoctial curves. The two Plates are drawn to a scale of $1'$ of arc to 0·35 of an inch, and Plate VI. contains the Singapore curves, which are drawn on a scale of $0'\cdot68$ of arc (the value of one scale division) to 0·35 of an inch. In the three Plates the zero line is the line of the magnet's most westerly position. The curve rising denotes a movement of the north pole of the magnet eastward. The curves themselves show, by the description of dotting, to which season they belong.

As the station curves have to be compared separately with Singapore, it will be preferable to consider first the principal changes of the Singapore curves shown in Plate VI. In Part 1 of Plate VI., which gives the mean curve of each month for three years, it appears that the minimum or westerly declination occurs at Singapore in December at 19 hours; in January at 20; in February at 21; in March (equinoctial month) a slight retrogression to 20; in April at 21; in May at 23; in June at 21;

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* The mean of the month being the mean of the whole number of observations; where there are but nineteen hours of observation, and these principally in the daytime, the mean of these for a mean temperature would unquestionably be too high; five of the hours of the night being omitted, the mean of the nineteen observed hours would be greater than the true mean; but this is not the case with the magnetic declination, the range being exceedingly small at night, and usually close upon the mean position of the needle.

in July and August at 23; in September at 22; in October at 21; and in November at 20 hours. If the seasons are projected in curves as in Part 2 of Plate VI., we find in winter the minimum at 20 hours; in spring at 21 hours; in summer at 23 hours; and in autumn back to 21 hours; agreeing in this with the spring curve, but differing very materially as regards the progression of the needle eastward in the afternoon; autumn and winter agreeing in this latter respect, and also spring and summer. The oscillation of the curve exhibits a much greater range during the winter months*; the autumn curve is next in extent of range and in the afternoon preserves a certain degree of parallelism with the winter curve; and both these curves have the afternoon maximum more decidedly expressed, and have also a higher maximum than in the morning. The reverse of this is the case with the spring and summer curves.

The mean curves of the three years exhibit a wonderful uniformity and almost total resemblance. There are two most decided maxima at 18 and at 3 or 4 hours, and one minimum at 21. There are besides two other minima at 10 and at 17 hours more faintly expressed. If we turn to the seasons, we find only one strongly defined maximum and minimum or a single progression in winter; in spring two strongly expressed maxima and one minimum; in summer and in autumn two maxima and two minima; and as these maxima and minima occur at different periods, the mean annual curve thus blends the leading characteristics of all, and presents accordingly a double, if not a triple progression.

On an inspection of the Plates, and on comparing them with the Singapore curves, we find that in Part 1 of Plate IV. the Moulmein April curve resembles no single curve in any one month at Singapore. The curve is that described by Declinometer No. III.; there are two minima at 17 and 1, and two maxima at 20 and 5 hours. Moulmein is about 8° north of the line of minimum intensity.

The next two in Part 1 of Plate IV. are the Sambooanga May curves of Declinometers Nos. I. and II.; comparing them with the same period at Singapore, we observe a certain degree of similarity, the morning maximum being at the same hour, the minimum being one hour later; the curves of the two declinometers differ slightly with each other: Sambooanga is on the line of minimum intensity.

The next curves are those of Batavia during the spring months; their resemblance to the spring curve of Singapore given in Part 2 of Plate VI. is very striking; the morning and afternoon maxima and the morning minimum being at the same hours at both places: Batavia is 14° south of the line of minimum intensity.

The next curves in Part 1 of Plate IV. are the Sarāwak summer curves; there is a considerable resemblance to the curves at the same period at Singapore, the morning minimum being one hour later; the position of Sarāwak is exactly the same as Singapore relatively to its position south of the line of minimum intensity. The last three curves of Plate I. are the Keemah curves of the latter end of June or commencement of July; their morning maximum and minimum at 19 hours, and at noon, correspond with the same periods at Singapore.

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* The sun is longer to the south of the line of minimum intensity than it is to the north. Singapore is in north latitude 1° 18′, and as the line of minimum intensity crosses the meridian of Singapore in about 8° north latitude, the sun is to the south of it considerably more than half the year.

At the top of Part 2 of Plate IV. containing the winter stations, the curves of the five declinometers are drawn to the same scale, viz. 1′ of arc to 0·35 of an inch: there may be seen from these curves, the extreme difference likely to occur amongst instruments observed nearly simultaneously; whilst these curves are similar, they are not identically the same; the observations were not taken at the same instant, but one after the other in the order of the declinometers*. The curves of Pulo Peesang in the same Plate, are similar to the Singapore February curve. The Carimon and Booāya curves are similar to one another, but the maximum in the afternoon is earlier than the corresponding maximum at Singapore. Part 1 of Plate V. is the continuation of the winter curves; the curves of the three declinometers at all the stations of Nicobar, Penang, Pulo Dinding, Batavia and Padang, agree well with the same winter period at Singapore.

In Part 1 of Plate V., at the hours of 6 and 7, there is observable in some instances a want of uniformity in the progression of the curve; in some instances no difference is perceptible, in others a minimum. On referring to Plate V. we find there is a minimum at Singapore in January, exactly similar to the minima shown in some of the curves of Part 1 of Plate V., and at the same hours.

In Part 2 of Plate V. are given the curves of the stations where the instruments were observed during the equinoctial months, both in spring and in autumn. The Madras curve, when compared with the Singapore curve, has its morning maximum and minimum at 20 hours and at noon; at Singapore at 18 and at 22 hours, two hours earlier. Madras is near the line of minimum intensity.

The observations at Bencoolen were taken for a few days at the end of August and at the commencement of September, it is therefore difficult to say to which month they belong; they agree well with the Singapore August curve. The next curves in the Plate are those of Batavia in March; they are exactly similar to the Singapore curve in March.

The Cocos curves taken in September agree well with the Singapore September curve; the form of the morning curve is identical, and the time of the afternoon maximum; but they differ in the afternoon maximum at the Cocos, having a greater range than the morning maximum; the progression of the magnet westward being subsequently more rapid till between the hours of six and seven, when there is the same faint minimum expressed as in the January curve at Singapore. Noting therefore those curves which are in accordance or differing but slightly from the Singapore curves during similar periods, we find only two which differ materially from the Singapore curves at similar periods of the year; one of the stations, Moulmein, being considerably to the north of the line of minimum intensity, the other, Madras (not differing so much), in its immediate vicinity. Sambooanga and Nicobar are indeed likewise close upon the line of no dip or minimum intensity, yet they agree generally with the Singapore curves. It is to be observed, that as we proceed north and approach the line of minimum intensity, the similarity to the Singapore curves becomes more faint; this may be seen on inspection of the Plates, where the most southerly stations, the Padang, Batavia and Cocos curves, agree exceedingly well with those at Singapore at similar periods*.

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* The observation of No. IV. at 3 A.M. has been omitted in the curve, as on referring to the observation book the series was found to be broken on one day in November; but the observation at 3 A.M. was entered, and as the scale reading was unusually low, it has reduced the mean reading at 3 A.M., or at 15 hours lower than it should be.

Bifilar Magnetometer.

The bifilar magnetometer is described at page 11 of Riddell's work; the apparatus is not very dissimilar to the unifilar; it consists of a tripod base with a fixed circular plate 5 inches in diameter, graduated so as to be read off by verniers to single minutes, carrying an upper revolving plate and two projecting arms for supporting the reading telescope and counterpoise weight; the magnet and bifilar suspension are inclosed, the former in a copper box, the latter in a suspension tube, 10 inches in length, carrying a circular plate, torsion circle and right and left hand screw-cylinder at its upper extremity, and the circle divided so as to be read off by verniers to 5′: the magnet is suspended by two portions of the same thread, and is maintained by a rotation of the upper extremities in a position at right angles to the magnetic meridian. The principal adjustments are the following, for the purpose of bringing the magnet, when suspended by the double thread, into a position at right angles to the magnetic meridian:—1st. To bring the line of detorsion of the threads to coincide with the magnetic meridian. This is effected by suspending the magnet by a single filament of untwisted silk; the telescope is turned until the centre division of the scale is on the wire; the instrument is clamped; the magnet is then introduced carefully with its bifilar suspension; the vernier of the torsion circle is turned until the centre division is again on the vertical wire of the telescope, and the plane of detorsion is in the magnetic meridian. The telescope which is fixed to the instrument is then turned 90° in azimuth; the vernier of the torsion circle is turned in the same direction through an angle (v) equal to 60°. The centre division of the scale is brought on the vertical wire by increasing or diminishing the interval of the threads; which is effected by turning the milled head of the screw-cylinder. The telescope is then turned back 90°; the torsion circle being turned back through the angle v; if the adjustment has been made correctly, the line of detorsion is again in the magnetic meridian;

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* Some want of similarity to the Singapore curve at those stations where any difference is observable, may possibly arise in some degree from want of the observations extending over a sufficient number of days; but not altogether, for at Madras, where a difference is perceptible, the declinometers were observed for more than a month.

the accuracy of the adjustment is tested by turning the telescope 180° in azimuth, so as to reverse the direction of the magnet, or bring its north end to the south. The telescope is again turned 90° at right angles to the magnetic meridian, so that increasing readings denote a decrease of force; the vernier of the torsion circle is turned till the central division of the scale is again on the vertical wire. The magnet is then perpendicular to the magnetic meridian, and the instrument is in adjustment. Thus much was necessary for understanding the following adjustments; those at the Cocos and at Batavia only are given; the adjustments at the rest of the stations being precisely similar, since the same angle of torsion $v=60°$ was selected for every station.

Adjustment of the Bifilar at Batavia.

The bifilar was adjusted in the afternoon of the 8th of November 1846 at 3 P.M. With the single suspension thread, the scale read 100; the horizontal circle 82° 23′. The bifilar apparatus was then carefully substituted.

	Horizontal circle.	Torsion circle.	Scale.
	° ′	° ′	
Magnet direct	82 23	53 50	100
Magnet direct.	172 23	113 50	100
Magnet direct.	82 23	53 50	99
Magnet reversed	262 19	53 50	99
Magnet direct.	172 23	113 50	92·3

Before taking down the instrument a fresh series was taken on the 7th of August 1847: premising that the reading 82° 23′ on the circle is direct, or the north end of the magnet to the north, and 262° 23′ is reverse, or the north end of the needle to the south; the following is the readjustment:—

	Horizontal circle.	Torsion circle.	Scale.
	° ′	° ′	
Magnet direct.	172 23	113 50	132·8
Magnet direct.	82 22	53 52	95·0
Magnet reversed	262 20	53 52	73·0
Magnet direct.	82 30	53 40	85·0
Magnet reversed	262 50	53 40	78·0
Magnet direct.	82 50	53 40	79·0
Magnet direct.	172 50	113 40	121·0
Magnet direct.	172 50	113 30	115·0
Magnet reversed	262 40	53 45	110·0
Magnet direct.	82 40	53 45	99·5
Magnet direct.	172 20	113 50	110·0

This small change of numbers is satisfactory, considering that the portable bifilar had been up for more than eight months.

Adjustment of the Bifilar at the Cocos.

The bifilar magnetometer was adjusted on the 27th of August, 1848. In the unifilar suspension the scale read 100·2; the bifilar suspension was then substituted.

	Horizontal circle.	Torsion circle.	Scale.
	° ′	° ′	
Magnet direct	50 27	233 55	99·3
Magnet direct	140 27	293 55	100·0
Magnet direct	50 27	233 55	96·5
Magnet reversed . . .	230 27	233 55	85·5
Magnet direct	140 17	293 55	95·3

The angle v or angle of torsion $=60°$. Thermometer 82°·6.

Value of a, *or of one Scale Division in terms of Radius.*

The variations of the horizontal intensity are obtained by multiplying the differences of the scale readings, or of their mean values (corrected for changes of temperature) by a constant coefficient

$$k=a\,.\cot v,$$

where a is the value of one scale division in terms of radius; as the horizontal circle by means of verniers read off to single minutes, I ascertained the value of a directly.

The first series gave the value of a' .	$=1'\cdot45$
The second series gave the value of a'	$=1\cdot38$
The third series gave the value of a' .	$=1\cdot43$
The fourth series gave the value of a'	$=1\cdot44$
Mean . .	1·433

The other method consisted in knowing the length, of one division of the scale, and of the radius,

where
$$a'=\frac{l}{2r}\times3437'\cdot75,$$

$$l=\frac{1}{70}\text{ of an inch},$$

$$r=17\cdot19\text{ inches},$$

$$a'=\frac{1}{70}\times\frac{3437\cdot75}{34\cdot38}=\frac{100}{70}=1'\cdot43.$$

1′·43 has been the angular value assumed, and the value of a in terms of radius is

$$\cdot0002909\times1'\cdot43=\cdot000415987,$$

and $k=a\,.\cot v=\cdot0002402$ the value of one scale division in terms of the force. The scale readings or mean values are corrected for temperature according to the formula

$$f=f'-(t'-t)\frac{q}{k},$$

where f' and f = observed and corrected readings,
t' and t = observed and standard temperature,
q = change of magnetic moment of the bar for 1° of FAHR.
$k=a \,.\cot v$, given above.

Coefficient of Temperature.—Determination of the Value of q.

The value of q was determined directly at all the principal stations by heat being gradually applied to the box at the time the instrument was in adjustment; by adopting this method before sunrise, the thermometer being at the lowest temperature, and the changes of force very trifling, I could ascertain at once the changes in the readings of the scale corresponding to the changes of the thermometer, and from thence the coefficient of temperature in terms of the force; a piece of cotton steeped in spirits of wine, ignited and applied carefully to the bottom of the box, gradually raised the interior temperature as indicated by the inclosed thermometer.

The following are the results at the commencement of August 1847 at Batavia; the results of the experiments at that station and at the Cocos are alone given, the results at all the other stations being precisely similar.

Coefficient of Temperature at Batavia.

Thermometer.	Differences.	Scale divisions.	Differences.
77°·6		76·8	
82·6	5·0	103·1	6·3
85·0	2·4	104·0	0·9
88·5	3·5	107·2	3·2
89·5	1·0	108·1	0·9
Sum	11·9		11·3

or one degree of temperature FAHR. for one scale division very nearly: this result agrees exactly with similar observations made at other stations.

Coefficient of Temperature at the Cocos.

To determine q or the coefficient of temperature the morning that the instrument was taken down, a piece of cotton dipped in spirit and ignited, was carefully applied to the bottom of the box, between 5 and 6 A.M., when the thermometer was at the minimum temperature and the changes of force but small, with the following results:—

Bifilar.		Thermometer.	
Scale.	Differences.	FAHR.	Differences.
86·1		75°·9	
90·8	4·7	79·2	3·9
96·5	5·7	89·9	10·7
98·5	2·0	90·6	0·7
101·7	3·2	90·6	0·0
Sum	15·6		15·3

Descending Scale.

97·0	4·7	83·6	7·0
92·0	5·0	79·6	4·0
89·6	2·4	77·6	2·0
87·3	2·3	76·6	1·0
Sum	14·4	Sum	14·0

Although the partial differences do not agree exactly, yet at the two extremes there is but little difference either in the ascending or descending scales of temperature. In the former, for an increase of 15°·3 of temperature the scale reading increased 15·6 divisions, and then fell back 14·4 scale divisions with a decrease of 14°; *q* therefore =·0002402 of the force. As these results are strictly in accordance with similar observations made at other stations, viz. at Sarāwak, Padang, &c., I have not had the least hesitation in assuming the value of *q* equivalent to one scale division: increasing scale readings denote an increase of temperature or decrease of force.

Oscillation or Variation of the Bifilar.

From page xlviii to lv inclusive, are given the oscillation, or more properly, the range of the horizontal intensity, given in detail in Table B; first, the mean oscillation of the horizontal intensity at all the stations comprised in the Survey; and at those stations where observations have been taken for more than a month, as at Batavia, Sarāwak, and Padang, the mean oscillation has been found from the monthly oscillations. At pages l and li are given the comparison of the observatory with the portable bifilar; but these are in scale divisions, and their values in terms of the force are different. The maximum range in the one case is 5·91 × ·000240 = ·0014, and in the other case 8·23 × ·000197 = ·0016 of the force; and the mean range is, of the portable bifilar, 2·48 × ·000240 = ·000595, and of the observatory bifilar 2·87 × ·000197 = ·000565 of the force*.

Singapore a Station for Comparison.

In order to have a fixed station where the hours of maxima and minima and extreme range may be known, the oscillation of the observatory bifilar is given in scale divisions at pages lii and liii for each of the seasons, for each of the months, and finally, the mean of each year.

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* It is evident that the great difference between the portable and observatory bifilar magnetometers takes place in the morning, or when the atmosphere is most saturated with moisture. The observatory bifilar magnet being well protected, and suspended by silver wire, would not be affected by humidity. The portable bifilar, on the other hand, being more exposed, and the magnet suspended by filaments of silk, it is to be presumed that the thread would be somewhat affected by damp. It may here be observed, that the same silk threads for the bifilar suspension were in use during nearly the whole period of the Survey; the suspension thread was formed by placing three filaments of silk together, their torsion having been previously taken out, and after running them through a very weak solution of gum and water, wiping them quite dry; the threads thus treated lasted for more than three years.

Table B.

From page lvi to lxxxv are contained the results of the bifilar at each of the sixteen stations in the Archipelago; the stations are given from the most northern proceeding to the most southern, the observations themselves being omitted.

At the top of each page is printed the name of the station and the astronomical time; then follow the coefficients, the value of one scale division, and the value of q (the change of magnetic moment of the magnet for 1° of temperature in terms of the force); X the value of the absolute horizontal intensity; the zero of the month, which is the mean of the month uncorrected; and the standard temperature, to which the mean of the month is corrected. The results of the bifilar at each station are given in horizontal columns: the first contains the sums of the scale readings; the second the means; the third the temperature correction to the lowest mean reading of the thermometer; and as increasing scale readings denote a decrease of force, the corrections will be all subtractive; the fourth contains the corrected means; the fifth contains the variation of the force in scale readings, the highest scale reading being the minimum of force and considered as 0; and the sixth contains these scale divisions in terms of the force, one scale division being $=\cdot 0002402$ of the force. The last vertical column, or $\frac{\delta X}{X}$, is retained, since it is the difference between the zero and the mean value of the daily means corrected to 80°. Immediately below this table is given the mean results of the thermometer, the bulb of which is inserted in the copper box containing the bifilar magnet; the first column includes the sums; the second the means; and the third column the differences from the lowest mean temperature.

Curves.

Part 1 of Plate VII. contains the curves of the Bifilar at the Singapore Observatory for each month of the year in scale divisions, each scale division being ·000197 of the force drawn to 0·35 of an inch.

Part 2 of Plate VII. is drawn to the same scale, and contains the mean of the four seasons, the mean of each year, and the general mean of the three years. The general march of these curves is exceedingly simple, having but one single progression; the maximum occurs at either 22 or 23 hours, the autumn and winter curves having generally their maximum at the former, the spring and summer curves at the latter hour. The minimum occurs at 10 or 11 hours, the minimum in autumn and in winter being likewise one hour earlier than the minimum in spring and summer; the extreme range in spring and autumn being greater than in summer and in winter.

Plate VIII. contains the curves at the stations where the portable bifilar was observed; three stations having been omitted, as the curves of these instruments observed but for a few days would cause some confusion by crowding the Plate: there appears to be exactly the same similarity observable between these and the Singapore curves to which they are referred, the maximum occurring sometimes as late as noon;

but the curves at the winter stations, as at Singapore during the same period, being distinguished by the intensity reaching its maximum earlier by one hour than in spring.

The curves in Parts 1 and 2 of Plate VIII. are both drawn to the same scale, viz. one scale division (=·000240 of force) to 0·29 of an inch. The curve rising denotes an increase of force. The curves of the bifilar showing the changes of horizontal intensity, appear to partake, every one, of the same character as the horizontal intensity at Singapore.

Table C.—*Dry and Wet Bulb.*

The dry and wet bulb instrument was made by Cary; it was small but accurate, and was in use throughout the Survey; but the wet-bulb thermometer was broken in crossing from Moulmein to Madras, and at the latter station another thermometer was substituted in lieu of it.

Explanation of Table C.

The results of the dry and wet-bulb thermometers are contained in Table C, from page lxxxvi to cvii inclusive. The mean variation or range of the dry thermometer is given in the General Table at pages lxxxvi and lxxxvii. At pages lxxxviii and lxxxix are given the mean variation of the wet thermometer.

At pages xc and xci are given the mean variation of the tension and vapour, and at pages xciv and xcv the mean degree of humidity of the air at the different stations.

The Tables containing only the mean results of the observations commence at pages xcvi and xcvii. The dry and wet-bulb thermometers at each station are given in succession.

In the first line of each set is given the mean of the number of days observed, in the second line the diurnal variation; then follows the mean of the wet-bulb thermometer, the diurnal variation, and lastly, the tension or elastic force of vapour in inches of mercury. The formula for the tension of vapour at the dew-point is

$$f''=f'-\frac{d}{88},$$

where d is the difference between the dry and wet bulb, and f' the tension of vapour at the temperature of the wet bulb. The value of f' is given in Table V. of the Report of the Committee of Physics and Meteorology of the Royal Society. The quantity of humidity in the air is found by dividing the tension of vapour at the temperature of the dew-point by the tension of vapour at the temperature of the air, and the result gives the number of proportional parts of in humidity the atmosphere; and it is by this method that the Table at pages xciv and xcv is constructed. The Tables of the dry and wet bulb are concluded at pages cvi and cvii.

Curves.

The curves corresponding to these Tables are laid down in Plate IX.; but the standard thermometer for the dry bulb is substituted. The curves are drawn to a scale of 10° of temperature to 0·35 of an inch.

Remarks.

The curve of the dry thermometer consists but of a single progression, the minimum being usually at 6 A.M., the maximum at noon. The curve of the wet thermometer consists likewise but of a single progression, its maximum and minimum occurring at the above times; the diurnal variation of the tension of vapour at pages xc and xci at the different Survey stations is very irregular; the curve usually consists of but a single progression, and is very similar to the wet bulb. The minimum is usually at 6 A.M., the maximum being at noon; the greatest range extending from 0·1 to 0·26 of an inch of the barometer. The irregularity occasionally indicated may be owing to the shortness of the period during which the instrument was observed. At those places where the dry and wet bulb were observed for more than a month the curve is regular. Throughout the Archipelago the minimum of tension of vapour usually occurs at 6 A.M., the maximum being at noon; a remarkable exception to this takes place at Madras, where the minimum is observed at noon; it appears to be explicable from the circumstance of the remarkable dryness of the air at Madras in August and September compared with that of the Archipelago generally; the dry thermometer at Madras ranges 15°·5 during the day from 6 A.M. to noon, or 1 P.M.; at which time it is at its maximum, as also the difference between the dry and the wet bulb. After 1 P.M. the dry thermometer gradually falls, and the difference between the dry and wet bulb diminishes, whilst the wet-bulb thermometer is still rising, very slowly, till 3 P.M.; consequently the tension of vapour increases so that the minimum elastic force occurs at noon, and the maximum some time in the afternoon.

The mean elastic force of the tension of vapour varies from 0·8 to 0·9 of an inch of the mercurial column.

The range of the humidity in the atmosphere, given at pages xciv and xcv, shows a single progression only, the minimum being at noon, the maximum early in the morning; in some instances the air is saturated with moisture at 6 A.M.

At Moulmein and at Madras, where the air was driest, and just previous to the N.E. monsoon at the latter and the S.W. monsoon at the former place, the mean quantity of humidity varied from 66 to 68 parts, complete saturation being 100; in the space included in the Survey the air is always loaded with moisture, and it is a tolerable approximation to the truth to state, that throughout the Archipelago the minimum quantity of humidity is 0·75, the maximum 0·85, and the mean quantity 0·80; complete saturation being $=1·0$.

The following Table contains the stations, their latitudes and longitudes; the mean date of observation; the number of days and the number of hours of each day the instruments were observed; the mean of the dry and wet thermometer, and of the tension of vapour; determined in two ways,—1st, by dividing by the number of hours during which the instruments were observed, and 2nd, by the system of equal intervals, a method for determining the mean value where the continuity of hourly observation is broken during the day, as generally occurred in the present instance.

Dr. Lloyd, in a paper on the mean results of observation, has shown that the error committed by taking the mean of any three equidistant hours as the mean temperature of the day, does not exceed 0°·26. In the following Table, in the column containing the mean by equal intervals, three sets of equidistant hours have been taken for finding the mean, viz. 3, 4, and 5 A.M.; 11 A.M., noon, and 1 P.M.; 7, 8, and 9 P.M. At those stations, where the instruments were observed during the twenty-four hours, a direct comparison can be instituted for ascertaining the correctness of this mode of finding the mean; at Sarāwak for three and at Batavia for four months, the means by each method are nearly identical. The mean temperature, as shown by the dry bulb, is about 80°; the mean of the wet bulb is between 76° and 77°; and the mean elastic force or tension of vapour throughout the space included in the Survey, varies from 0·8 to 0·9 of an inch of the barometric column.

Table showing the Means of the Dry and Wet Thermometers and of the Tension of Vapour, by Dr. Lloyd's method of equal intervals, and by dividing by the number of hours observed, and the difference in each case.

Station.	Latitude.	Longitude.	Mean date corresponding to the	No. of days.	No. of hours.	Dry Thermometer.			Wet Thermometer.			Tension of Vapour.		
						Mean by equal intervals.	Mean by number of hours.	Diff.	Mean by equal intervals.	Mean by number of hours.	Diff.	Mean by equal intervals.	Mean by number of hours.	Diff.
Moulmein ...	16° 29′ 46″ N.	97° 45′ 30″ E.	Mid. of April.	7	19	86·1	88·3	+2·2	78·0	78·5	+0·5	·853	·846	−·007
Madras	13 04 09	80 16 00	Begin. of Sept.	34	19	84·3	85·2	+0·9	76·6	76·6	0·0	·811	·801	−·010
Nicobar	9 10 12	92 48 23	Begin. of Feb.	5	19	79·3	80·5	+1·2	75·8	76·6	+0·8	·839	·855	+·016
Sambooanga.	6 54 20	122 13 45	End of May.	6	19	80·5	82·2	+1·7	76·4	77·6	+1·2	·847	·877	+·030
Pulo Penang.	5 25 36	100 24 38	End of Jan.	5	19	80·6	81·2	+0·6	77·0	77·3	+0·3	·873	·876	+·003
Pulo Dinding	4 12 48	100 32 52	End of Jan.	3	19	82·7	83·2	+0·5	76·6	77·1	+0·5	·838	·844	+·006
Sarāwak......	1 33 54	110 29 00	Mid. of June.	26	24	79·8	79·6	−0·2	77·8	77·7	−0·1	·913	·911	−·002
			Mid. of July.	27	24	79·0	78·9	−0·1	76·9	76·9	0·0	·886	·885	−·001
			Mid. of Aug.	19	24	79·0	78·8	−0·2	76·7	76·6	−0·1	·877	·874	−·003
Keemah	1 21 55	125 07 59	End of June.	10	19	80·4	81·1	+0·7	76·6	77·0	+0·4	·863	·865	+·002
Pulo Peesang	1 27 53	103 19 15	Mid. of Jan.	5	18	80·6	80·8	+0·2	77·5	77·9	+0·4	·892	·905	+·103
Singapore ...	1 18 32	103 56 30	End of Nov.	16	19	80·3	80·3	0·0	77·1	76·9	−0·2	·876	·869	−·007
			Begin. of Dec.	14	19	80·2	80·1	−0·1	76·4	76·2	−0·2	·851	·843	−·008
Padang	0 58 58 S.	100 31 15	End of Oct.	13	19	78·5	79·7	+1·2	75·9	75·7	−0·2	·816	·828	+·012
			Mid. of Nov.	26	19	79·2	80·2	+1·0	75·4	76·0	+0·6	·828	·835	+·007
			Mid. of Dec.	26	19	79·5	80·6	+1·1	75·3	75·9	+0·6	·820	·826	+·006
			Begin. of Jan.	13	19	79·8	80·9	+1·1	76·1	76·7	+0·6	·848	·855	+·007
Bencoolen ...	3 53 54 S.	102 28 45	Begin. of Sept.	5	19	78·1	79·3	+1·2	76·3	77·0	+0·7	·869	·865	−·004
Batavia	6 09 52	106 58 00	Mid. of Nov.	19	24	80·3	80·2	−0·1	76·8	76·8	0·0	·866	·866	·000
			Mid. of Dec.	26	24	79·7	79·7	0·0	76·6	76·5	−0·1	·866	·859	−·007
			Mid. of Jan.	25	24	79·5	79·8	+0·3	76·3	76·4	+0·1	·852	·854	+·002
			Mid. of Feb.	24	24	79·5	79·5	0·0	76·8	76·8	0·0	·875	·874	−·001
			Mid. of March	27	19	80·5	81·2	+0·7	77·2	77·6	+0·4	·882	·888	+·006
			Mid. of April	26	19	80·5	81·1	+0·6	77·0	77·3	+0·3	·874	·877	+·003
			Mid. of May	26	19	80·2	80·9	+0·7	76·5	76·8	+0·3	·858	·859	+·001
			Mid. of June	26	19	80·0	80·7	+0·7	75·4	75·7	+0·3	·815	·817	+·002
Cocos	12 05 38	96 50 30	Mid. of Sept.	26	19	79·6	79·5	−0·1	75·0	75·0	0·0	·802	·803	+·001

Some doubts have arisen as to the value of the dry and wet bulb as an instrument for measuring approximately the degree of humidity in the atmosphere; and Colonel Sykes, F.R.S., has mooted the question in a very interesting paper on the Meteorology of India, which has been lately published in the Philosophical Transactions: one of the sources of error supposed to be peculiar to this instrument, although easily remedied if discovered, is the too close proximity of the wet bulb to the dry bulb, the consequent depression of the latter, the difference of the two thermometers or the value of *d* consequently diminishing, and the resulting tension of vapour greater than it ought to be. I do not know the exact distance that the two bulbs were apart in Cary's little instrument; at most 2 to 2½ inches, and both fixed to one stem. The following are the results of a comparison between the Standard Thermometer and Dry-Bulb Thermometer at all the stations; and it will be seen, on inspection of the following Table, how very slight are the differences between the two thermometers[*].

Station.	Month.	Mean by the number of hours.		Difference.
		Standard Thermometer.	Dry Thermometer.	Standard – Dry Thermometer.
Moulmein	April	88°·4	88°·3	+0°·1
Madras	September ...	85·2	85·2	0·0
Nicobar	February	80·9	80·5	+0·4
Sambooanga	May	82·5	82·2	+0·3
Pulo Penang	January	81·7	81·2	+0·5
Pulo Dinding......	January	82·6	83·2	–0·6
Sarāwak	June............	79·6	79·6	0·0
	July	78·8	78·9	–0·1
	August.........	78·7	78·8	–0·1
Keemah	June............	81·5	81·1	+0·4
Pulo Peesang......	January	81·5	80·8	+0·7
Singapore	December ...	79·8	80·2	–0·4
Padang	October	80·5	79·7	+0·8
	November ...	80·8	80·2	+0·6
	December ...	81·3	80·6	+0·7
	January	81·7	80·9	+0·8
Bencoolen	September ...	79·3	79·3	0·0
Batavia	November ...	80·3	80·2	+0·1
	December ...	79·8	79·7	+0·1
	January	80·1	79·8	+0·3
	February	79·6	79·5	+0·1
	March	81·3	81·2	+0·1
	April	81·3	81·1	+0·2
	May............	81·2	80·9	+0·3
	June............	81·0	80·7	+0·3
Cocos	September ...	79·2	79·5	–0·3

Standard Barometer and Portable Barometer, and Adjustments.

At the principal stations the large Standard Barometer was in use; but at some the Portable Barometer was observed, from the greater trouble and risk attending the carriage of the Standard. The Standard was used at the following places:—at the Cocos, at Batavia, at Padang, at Singapore, at Keemah, at Sarāwak, and at Sambooanga.

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[*] At Padang the differences are the greatest, and as these appear to be constant at the same station, they are probably due more to the relative position of the Standard Thermometer and Dry Bulb, than to the proximity of the latter to the Wet Bulb.

The Standard Barometer was made by NEWMAN; diameter of the tube 0″·532; the correction to be applied for capillary action +·003″. The zero-point consists of a fine conical point brought to touch the surface of the mercury; this is an adjustment which we are instructed to make at each observation; but throughout the Survey the conical point or zero-point, being once accurately adjusted, was never subsequently touched; the capacity of the cistern is so much greater than that of the tube, that the variation of the barometer in the Tropics being not more than $\frac{1}{10}$th of an inch, the level of the cistern would be but little affected thereby. The internal diameter of the cistern is about 4 inches; the relative areas of the tube and cistern are as 0·25 to 16, or as 1 to 64; and as the barometric column varies to the extent of $\frac{1}{10}$th of an inch, the cistern would be affected to $\frac{1}{640}$th of an inch, and the quicksilver therefore would rise above or sink below the mean position $\frac{1}{1280}$th of an inch; a space which a very accurate observer might be able to detect between the conical point and a very bright surface, but not with the quicksilver in the barometer now in question, as the surface was covered with a thick film, and the glass cistern was somewhat dingy; for this reason, after one adjustment very carefully made at noon, this being about the time of the mean, the zero point of the barometer was not further touched during the whole series of observations; and I never could detect at the hour of maximum and minimum, viz. at 9 or 10 A.M., and at 3 or 4 P.M., any difference in the relative position of the conical point to the surface of the mercury, and therefore no correction has been applied to the neutral point determined at noon.

The Standard Barometer was by no means tight, and therefore imperfectly portable: when moving from one place to another, the quicksilver was constantly escaping by the wooden collar at its junction with the tube; this loss was supplied with fresh mercury, strained through leather and poured into the cistern; and as no air could ever be detected in the tube, the instrument was perfectly serviceable throughout the whole of the Survey. The leakage at the collar was by no means peculiar to this barometer, as I have discovered it in others by the same maker.

The Portable Barometer, made by CARY, was in use at a few stations during the Survey; I had filled it very carefully at Singapore; in the comparisons made with it and the Singapore Standard Barometer, it was generally a little lower; but as it had not exactly the same range, the correction would not be constant, and therefore no correction has been applied. The diameter of the tube, which dimension I obtained from Mr. CARY, is between 0·27 and 0·28 of an inch; the correction to be applied for capillary action = +0″·023; the scale is marked on brass to the twentieth of an inch, and can be read off by a vernier to the thousandth of an inch, being similar in this respect to the Standard Barometer. The gauge-point or zero-point is a slit in the iron cistern at its upper surface; the quicksilver, being pressed up by means of a screw applied to the leathern bottom of the cistern, is raised till the light is no longer seen through the slit, and the level of the quicksilver in the cistern is then at that point from which the scale is laid off; there is therefore no correction for neutral point: this instrument was well made and well finished, and has yielded at all times exceedingly satisfactory results.

Explanation of the Table D.

The observations made with the barometer are contained in Table D. from page cviii. to cxxi inclusive.

At pages cviii and cix are given the mean variation or oscillation of the barometer; at pages cx and cxi the mean variation of the gaseous pressure or dry column of air.

From page cxiv to cxxi inclusive, are contained the mean results of the barometer at each station: each set contains in the first line the mean of the barometer uncorrected; then the barometer corrected to 32°; and thirdly, the gaseous pressure which is deduced by subtracting from the barometric column the tension of vapour.

Curves.

The curves of the barometer corrected to 32°, are contained in Plate X. The curves are drawn to a scale of ·01 of an inch of barometric pressure to 0·30 of an inch linear measure: the curve rises with the increase of pressure.

Plate XI. contains the curves of the variation of gaseous pressure drawn to the same scale, viz. ·01 of an inch of barometric pressure to 0·30 of an inch linear measure: the curve rises with increase of pressure.

Remarks.

The barometric curve has a double progression, a principal maximum and minimum at 9 A.M., and at 3 and 4 P.M.; and a secondary maximum and minimum at 10 P.M. and 4 A.M. The intervals between the successive maxima and minima are nearly equal, and the degree of parallelism between all the curves is very striking; the range or variation appears to be nearly similar, and the hours of maxima and minima are identical; one exception occurs at Madras, the maximum taking place at the same time, but the minimum at 5 P.M., two hours later than the minimum generally throughout the Archipelago.

The variation of the gaseous pressure is given in Plate XI.; it appears to have, like the barometric curve, a double progression, but the principal maximum and minimum occur earlier; the A.M. minimum is more faintly expressed, with an interval of three or four hours only between the morning minimum and the morning maximum. The curve is likewise more irregular than the barometric, and the range is greater; only a few of the curves are given, to prevent confusion from over-crowding, and those places have been selected where observations have been taken for upwards of a month.

The following Table contains, by Dr. Lloyd's method of equal intervals, the means of the barometer uncorrected, the barometer corrected to 32°, and the mean of the gaseous pressure; each mean being the result of three sets at equidistant hours, viz. 3, 4, 5 A.M.; 11 A.M., noon, 1 P.M.; 7, 8. and 9 P.M. The mean throughout the Archipelago, of the barometer corrected, is 29·80 to 29·90 English inches; the range or variation being a little more than a tenth of an inch. The mean of the gaseous pressure is about 29 inches; the variation being nearly double that of the barometric pressure, and amounting to about two-tenths of an inch.

Station.	Latitude.	Longitude.	Mean date corresponding to the	No. of days.	No. of hours.	Mean of the barom. uncor-rected.	Mean of the barom. corrected to 32°.	Mean of gaseous pressure.
						28 English inches + the numbers in the Table.		
	° ′ ″	° ′ ″				in.	in.	in.
Moulmein ...	16 29 46 N.	97 45 30 E.	Middle of April	7	19	1·897	1·766	0·913
Madras	13 04 09	80 16 00	Beginning of September	34	19	1·807	1·681	0·806
Nicobar	9 10 12	92 48 23	Beginning of February	5	19	2·052	1·937	1·098
Sambooanga	6 54 20	122 13 45	End of May	6	19	1·997	1·863	1·013
Pulo Penang	5 25 30	100 24 38	End of January	5	19	2·005	1·885	1·013
Pulo Dinding	4 12 48	100 32 52	End of January	3	19	2·114	1·994	1·156
Sarāwak	1 33 54	110 29 00	Middle of June	26	24	1·997	1·864	0·952
			Middle of July	27	24	1·985	1·854	0·968
			Middle of August	19	24	2·009	1·879	1·002
Keemah	1 21 55	125 07 59	End of June	10	19	2·016	1·880	1·018
Pulo Peesang	1 27 53	103 19 15	Middle of January	5	18	2·074	1·955	1·080
Singapore ...	1 18 32	103 56 30	End of November	16	19	2·050	1·914	1·038
			Beginning of December	14	19	2·037	1·905	1·053
Padang	0 58 58 S.	100 31 15	End of October	13	19	2·045	1·912	1·097
			Middle of November ...	26	19	2·040	1·907	1·079
			Middle of December ...	26	19	2·005	1·873	1·053
			Beginning of January...	13	19	2·017	1·883	1·035
Bencoolen ...	3 53 54	102 28 45	Beginning of September	5	19	1·974	1·862	0·993
Batavia	6 09 52	106 58 00	Middle of November ...	19	24	1·994	1·860	0·992
			Middle of December ...	26	24	1·995	1·862	0·996
			Middle of January	25	24	2·001	1·868	1·016
			Middle of February ...	24	24	1·988	1·856	0·981
			Middle of March	27	19	2·015	1·876	0·994
			Middle of April	26	19	2·010	1·875	1·001
			Middle of May	26	19	2·009	1·873	1·016
			Middle of June	26	19	2·003	1·868	1·054
Cocos	12 05 38	96 50 30	Middle of September ...	26	19	2·089	1·958	1·155

Standard Thermometer.

This instrument, made by Newman, was used in the observatory at Singapore till the end of the year 1845, and I then took it with me on the Survey. The scale is marked off to half-degrees, each degree being 0·11 of an inch, so that the thermometer is read off easily to tenths. In marking off the scale, an error has been committed in omitting one degree from 90° to 95°, so that 95° is only 94°; the divisions of the scale are all equal, and therefore the mistake occurring in the numbering only, one degree has always been deducted from the observed reading of the thermometer when it stood at 95° or above that temperature. The standard thermometer was usually attached to the pole of the tent, or else to the back of the post to which the standard barometer was fixed.

Explanation of Table E.

The results of the observations with the Standard Thermometer are contained in Table E., from page cxxii to cxxix inclusive. At pages cxxii and cxxiii are given the diurnal variation of the Standard Thermometer. The remainder of Table E. contains the mean results of the Standard Thermometer; each set contains, in two lines, the mean hourly readings and the diurnal variation of the Standard Thermometer.

Curves.

The curves of the Standard Thermometer have already been noticed in speaking of the dry bulb.

Remarks.

There is but one maximum and one minimum in the twenty-four hours, viz. at 2 and at 18 hours. The oscillation or range varies, but the smallest is at Singapore, where the standard thermometer was placed inside the observatory, but exposed to a current of air passing through the building. The range was greatest at Moulmein and at Padang; but as at these observatories the observations were taken under canvas only, the direct influence of the sun's rays was very great. At Moulmein the temperature of the observatory was so hot as to be nearly unbearable, although the thermometer only reached 105°: at the commencement of the Introduction I gave a short statement of the materials with which each observatory was constructed, that, in recording the height of the thermometer, the circumstances under which it was observed should be taken into consideration: the difficulty in tropical climates of ascertaining correctly the temperature of the air is very great; the most difficult points to be determined appear to be; the size of the building, the height of the roof and the nature of the materials of which it is composed, in order that the thermometer shall give only the temperature of the air, and not in addition that of the building in which it is placed. If the building is small, if the roof is low and of good conducting materials, such as slates or tiles, the thermometer is too high by day, and probably too low at night; the only condition appears to be a lofty room, of large size, well-ventilated, and double-roofed with non-conducting materials. The observatories at Sarāwak, Singapore and Batavia were excellent in this respect: at all other stations the thermometer was not sufficiently screened from the above liabilities to error, and therefore the daily curve at some of the stations is too high, whilst the mean temperature is nearly correct.

Solar and Terrestrial Radiation Thermometers.

In addition to these thermometrical observations, there was likewise in use, at the conclusion of the Survey, a Solar Radiation Thermometer, the bulb of which was tinged of a dark purple colour, although not absolutely black. This instrument was placed on a table outside the tents and freely exposed to the sun. After the instruments in the tent were observed, the solar radiation thermometer was read off hourly, from 7 A.M. to 4 or 5 P.M., and the maximum of the day recorded, with the time at which it was observed, being generally 11 A.M., noon, or 1 P.M.

The minimum self-registering thermometer was placed on a table outside the tent at night, and the minimum temperature shown by the index read off at 7 A.M.

The subjoined Table contains the maximum solar radiation, and the mean at each station; the minimum and the mean of the self-registering thermometer exposed at night; and lastly, the mean of the standard thermometer, by dividing by the number of observations, and likewise by Dr. Lloyd's method of equal intervals, each result being the mean of three sets, at 3, 4, 5 A.M.; 11 A.M., noon, 1 P.M.; and 8, 9, 10 P.M.

Station.	Latitude.	Longitude.	Mean date corresponding to the	No. of days.	No. of hours.	Solar Radiation.		Terr. Radiation.		Standard Thermometer.		
						Maximum.	Mean.	Minimum.	Mean.	Mean by equal intervals.	Mean of the whole set.	Diff.
Moulmein	16° 29′ 46″ N.	97° 45′ 30″ E.	Middle of April.	7	19	111°·5	110°·0	70°·2	71°·9	86°·0	88°·4	+2°·0
Madras	13 04 09	80 16 00	Beginning of Sept.	34	19	115·0	104·7	74·0	76·6	84·3	85·2	+0·9
Nicobar	9 10 12	92 48 23	Beginning of Feb.	5	19	102·0	98·9	67·7	68·4	79·9	80·9	+1·0
Sambooanga	6 54 20	122 13 45	End of May.	6	19	104·7	102·6	71·4	72·3	80·7	82·5	+1·8
Pulo Peenang......	5 25 30	100 24 38	End of January.	5	19	105·8	103·0	70·8	71·9	81·3	81·7	+0·4
Pulo Dinding......	4 12 48	100 32 52	End of January.	3	19	113·8	110·9	70·6	72·2	82·4	82·6	+0·2
Sarāwak	1 33 54	110 29 00	Middle of June.	26	24	......	......	......	......	79·8	79·6	−0·2
			Middle of July.	27	24	......	......	68·6	71·8	79·0	78·8	−0·2
			Middle of August.	19	24	......	......	69·3	71·6	78·8	78·7	−0·1
Keemah	1 21 55	125 07 59	End of June.	10	19	112·2	108·6	68·3	70·3	80·9	81·5	+0·6
Pulo Peesang	1 27 53	103 19 15	Middle of January.	5	18	......	......	......	......	81·3	81·5	+0·2
Singapore	1 18 32	103 56 30	Beginning of Dec.	30	19	107·7	98·3	67·6	71·1	79·8	79·8	0·0
Padang	0 58 58 S.	100 31 15	End of October.	13	19	......	......	69·4	70·6	79·2	80·5	+1·3
			Middle of November.	26	19	......	......	69·8	71·1	79·7	80·8	+1·1
			Middle of December.	26	19	......	......	68·5	70·8	80·3	81·3	+1·0
			Beginning of Jan.	13	19	......	......	......	......	80·5	81·7	+1·2
Bencoolen	3 53 54	102 28 45	Beginning of Sept.	5	19	......	......	69·8	71·2	78·4	79·3	+0·9
Batavia	6 09 52	106 58 00	Middle of November.	19	24	......	......	69·2	72·4	80·5	80·3	−0·2
			Middle of December.	26	24	......	......	69·8	72·6	80·3	79·8	−0·5
			Middle of January.	25	24	......	......	68·5	71·1	80·0	80·1	+0·1
			Middle of February.	24	24	......	......	70·7	72·6	79·6	79·6	0·0
			Middle of March.	27	19	......	......	69·2	72·9	80·9	81·3	+0·4
			Middle of April.	26	19	......	......	69·2	71·5	80·8	81·3	+0·5
			Middle of May.	26	19	......	......	67·4	69·9	80·7	81·2	+0·5
			Middle of June.	26	19	......	......	......	......	80·5	81·0	+0·5
Cocos or Keelings	12 05 38	96 50 30	Middle of September.	27	19	105·5	99·5	72·2	74·9	79·2	79·2	0·0

Survey, and Instruments employed.

The observations connected with the Survey relate to absolute determination, such as latitude, longitude, dip, horizontal intensity, and variation or magnetic declination, and this is the order in which the subject will be treated; but previously, it may be as well to state in a few words, how the Survey on land was conducted. On my arrival at a station I had my small tent pitched, for the reception of the magnetic instruments; this was generally put up the evening of my arrival; and the next morning at daybreak I commenced observing. The instruments in use were a 6-inch dip circle, a portable declinometer for magnetic declination and intensity, an altitude and azimuth instrument, made by Robinson, and sent out on the first establishment of the observatories, and a chronometer (824), Arnold and Dent, which had been so long in use, that it was not to be trusted for a fixed rate. The first instrument set up was the portable declinometer; this instrument was tedious to adjust, in consequence of the suspension thread, to support the collimator magnet, being stronger than there was occasion for so as to obviate the necessity of frequent renewal; the stirrup with the brass weight attached to the suspension thread, was allowed to swing for more than a couple of hours; the opportunity was taken during the interval of determining the dip with four needles. At 8½ a.m. the dip observations being completed, the stirrup of the portable declinometer, by frequent small twists of the torsion circle having been brought to rest in the magnetic meridian, was finally in adjustment. The brass weight for taking the torsion out of the threads was removed, and the collimator magnet placed in the stirrup. The altitude and azimuth instrument was adjusted in rear of the collimator magnet, and in the direction of its axis, but always to the south of it, at a distance of about 4 feet. By 9 a.m., this instrument being also in adjustment, the copper damper was placed carefully in the oaken box containing the collimator magnet, by which the latter in a few minutes was brought to rest. During this short interval three or five altitudes of the sun were taken with the sextant and artificial horizon, and the corresponding times with the chronometer.

At 9½ a.m., the collimator magnet being at rest, altitudes of the sun were observed with the altitude and azimuth for magnetic declination or variation; these being finished, observations for horizontal intensity, both of deflection and vibration, were proceeded with and generally finished at 11½ a.m. At noon circummeridional altitudes of the sun were observed for latitude, and in the afternoon, if fine, equal altitudes were taken to confirm the morning sights. The tent was then taken down, the instruments packed up, and generally sent off in the evening, if practicable, to the next station.

The following is a rough diagram (not drawn to scale) of the relative positions of the instruments in the tent:—

a. The dip circle, removed at 8½ a.m.

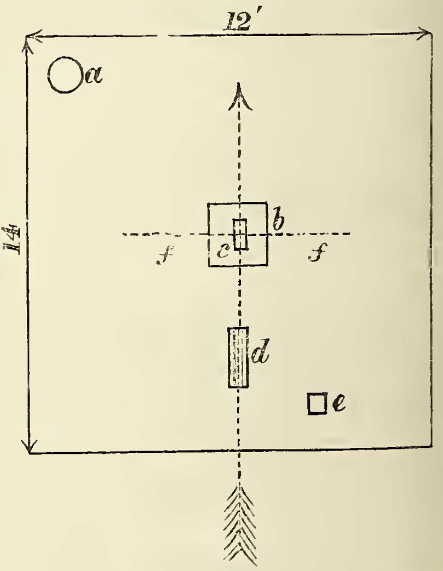
b. Declinometer-box, with deflecting arms, *f*, *f*, for the determination of the absolute horizontal intensity.

c. Collimator magnet, in declinometer-box, suspended by three or four fibres of untwisted silk.

d. Telescope of altitude and azimuth.

e. Position of table on which the chronometer was placed.

Dimensions of the tent 12 × 14 feet.



Latitude.

The observations for latitude were usually taken, if the weather permitted, a few minutes both before and after noon: the instrument being previously in adjustment, the altitudes and times corresponding were taken immediately before or at noon, three times with the vertical circle direct, and three times at or immediately after noon with the vertical circle reversed; the latitude was found from these altitudes reduced to the meridian.

A Table of the Latitudes at the Cocos or Keeling Islands is subjoined, merely as a specimen of the working of the instrument; it is necessary to state, that in the observations for latitude by taking altitudes of the sun, the error of collimation was corrected by the reversal of the telescope on its axis; but in finding the latitude from altitudes of the stars, the instrument was clamped in the meridian, the altitude of the star taken as it passed the centre wire, and a correction applied for the error of collimation.

Date.	Latitude ☉	Date.	Latitude ✱.	Name of ✱.
	° ′ ″		° ′ ″	
August 26......	12 05 21 S.	August 28	12 05 18 S.	α Herculis.
27......	06 15		05 32	α Ophiuchi.
31......	06 10	September 10	05 07	γ Aquilæ.
September 7......	05 30		05 30	α Aquilæ.
15......	05 46		05 40	ε Aquarii.
23......	05 19		05 20	μ Aquarii.
26......	06 07	12	06 20	p Piscium.
27......	05 58		05 40	s Piscium.
		13	05 10	s Piscium.
		14	05 30	μ Ceti.
			05 30	o Piscium.
		15	05 45	ξ 2 Ceti.
			05 20	μ Ceti.
		16	05 10	λ Tauri.
		17	05 28	γ Aquilæ.
			05 30	α Aquilæ.

Longitudes.

The longitudes were found chiefly from sights; but I am afraid they are not much to be depended upon, in consequence of the rate of the chronometer frequently changing; the following is the method I adopted, at any two places far apart, where I was able to determine the rate. I took the mean rate and applied it to the observations for longitude at the intermediate stations. At some of the principal points, where I remained for a considerable time, I was able to obtain sights of moon-culminating stars for longitude, as well as lunar distances; the longitudes obtained from moon-culminating stars with the altitude and azimuth instrument, were necessarily very rough, but they served as a check upon the chronometer.

The following observations were taken at the Cocos:—

Date.	Stars and Moon.	Mean difference between Greenwich and Cocos, ✳ and ☾.	Resulting Longitude East.
		m s	h m s
Sept. 6......	θ Ophiuchi, ☾ I, μ Sagittarii, λ Sagittarii	14 09·86	6 27 18
8......	o and π Sagittarii, ☾ I, α 2 Capricorni	14 49·08	6 28 36
9......	α 2 Capricorni, ☾ I, ε and μ Aquarii	15 00·13	6 26 31
10......	ε and μ Aquarii, ☾ I, γ and δ Capricorni	15 11·14	6 27 48
12......	☾ I, *p* and *s* Piscium	15 20·05	6 27 05
13......	*s* Piscium, ☾ II.	15 27·42	6 26 45
14......	☾ II., μ and *o* Piscium	15 44·21	6 28 23
15......	*o* Piscium, ☾ II., ζ, ε and μ Ceti......................	15 59·04	6 27 43
		Mean Longitude	6 27 22

The mean longitude resulting from nine sets of lunar distances, was $6^{h}\ 26^{m}\ 47^{s}$: but these were not to be trusted, as the sum of the distance and the true altitudes of the ⊙ and ☾ at each observation amounted to 180°, very nearly. I consider it my duty, however unsatisfactory may be the observations, to publish one set in detail, as their value, small or large, may thus be inferred; although but little could be expected from a small altitude and azimuth on an ordinary table stand, as a substitute for a transit instrument, it was better to depend upon these observations than upon the chronometer, which had been long in use, and which yielded such rates, on successive days at the Cocos, as the following:—

$+7^{s}\cdot7,\ +9^{s}\cdot1,\ +11^{s}\cdot4,\ +8^{s}\cdot8,\ +7^{s}\cdot8,\ +6^{s}\cdot7,\ +6^{s}\cdot7,\ +8^{s}\cdot4,\ +8^{s}\cdot9,$
$+8^{s}\cdot7,\ +8^{s}\cdot9,\ +9^{s}\cdot1,\ +9^{s}\cdot5,\ +12^{s}\cdot2,\ +10^{s}\cdot4,\ +9^{s}\cdot9,\ +8^{s}\cdot6,\ +8^{s}\cdot9;$

the mean rate being $+8^{s}\cdot19$; of course no dependence could be placed upon such rates as these for the longitude.

Dip or Inclination of the Needle.

The Dip Observations are contained in Table F., from page cxxx to cxxxix inclusive.

On commencing the Survey in 1846 I was not furnished with a dip circle; a Fox's dip circle had been stolen from the observatory at the latter end of 1845, and three dip circles had been sent, in 1844, to England to Mr. Barrow, but they had not then reached Singapore, having been detained at Bombay through some mistake.

In March 1846 I received a dip circle with four needles from Mr. Taylor, the then astronomer at Madras: the needles were very inferior; one of them, A 1 L, having a difference of 24° reading on the reversal of the poles: the observations with this needle should perhaps have been omitted. The correction to be applied to A 1 L was 28′, with only half the value assigned to it, which has been given to each of the other needles, and each recorded observation with the Madras circle is the mean of forty-eight readings. With the Madras dip circle I took observations at Singapore, in

Borneo, at Batavia, and the western portion of the island of Java; these observations are included in pages cxxx and part of cxxxi.

On my return to Batavia at the latter end of the year, I found the three dip circles, which, having been thoroughly repaired, had been sent out by Mr. Barrow; the observations are contained in pages cxxxii and cxxxiii*.

Before commencing the survey of part of Sumātra, I determined to make use of needles with their poles unchanged, and to apply a correction, if necessary, for the true dip, as the large magnets for reversing the poles were often brought in dangerous proximity to the small cylindrical magnets used on the Survey. Having determined the true dip at Padang with nine needles, I fixed upon Dip Circle No. 1 with three needles, A 1, A 1 L and A 2 L, by first combining A 1, A 1 L, and subsequently A 1 L with A 2 L.

The mean result gave me as a correction . . . +8′·9
The mean of the nine needles with the poles changed . = −18° 31′·7
With the three combined as above and the poles unchanged 18° 40′·6
+8′·9

So that in the Survey in Sumātra, at page cxxxv in the last column, is given the corrected dip by subtracting 8′·9 from the mean of the three needles.

This series of three needles with poles unchanged and correction +8′·9, terminates at Nātal in Sumātra.

On my return to Singapore in February 1848, a long series of observations was taken, to determine by direct means the difference in the inclination A.M. and P.M., the former being taken with four needles at 10 and 11 A.M., the hours of maximum horizontal intensity, and the latter at 4 P.M., the hour of minimum horizontal intensity; the poles of the needles employed were changed at the commencement or the termination of each day's observation, so that the A.M. and P.M. observations were taken with the needles under the same magnetic condition; two days consequently were necessary for the determination of the true dip. From the mean result at page cxxxiv, there is a difference of 0′·8 increase in the afternoon, whilst the probable error of the mean value of each set is the same, viz. ±0′·4.

At the Cocos or Keeling Islands, the poles of the needles of Box No. 1 being unchanged, the correction to be applied to the three needles was as follows:—for A 1, −3′·0; for A 1 L, −6′·0; and for A 2 L, −3′·0; equal value in determining the mean has however been given to these needles, as double the number of readings have been taken.

At Pulo Dinding the poles of the needles of Dip Circle No. 1 were again changed, when it appeared that for A 1, poles direct and poles reversed were nearly the same; for A 1 L, the correction to be applied to poles direct was − 16′·3, and for A 2 L, the correction to be applied was − 2′·0; and these have been the corrections made use of at page cxxxv for Dip Circle No. 1 at Singapore.

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* There were originally four needles, A 1, A 2, A 1 L, A 2 L, to each dip circle numbered 1, 2 and 3; but three of the needles having soon become rusty, there were left three needles with Dip Circle No. 1, four needles with Circle No. 2, and two needles with Circle No. 3; and it was in consequence of Dip Circle No. 2 being complete, that it was used for the survey of Java.

Inclination or Dip at Sea.

The observations at sea were made with a Fox's Dip Circle; the separate observations are not given, as they would occupy too much space; but the mean results are contained in a General Table at page cxxxvii, where the observations at sea have been corrected for the direction of the ship's head, for index correction (the poles being unchanged), and corrected with the whole of the dip observations to a mean epoch, viz. January 1, 1848. The details of swinging the ship, of finding the index correction, are not included in this report, but one example is given of swinging the Schooner at Keemah.

Correction for Direction of Ship's Head.

There were in all thirteen observations: from north to east, three; east to south, three; south to west, three; and west to north, four.

	Ship's Head.	Dip.	Mean Dip.
North to East	N.	11° 37′·5	11° 37′·2
	N.E.	11 35·0	
	E.N.E.	11 39·1	
East to South	E. by S.	11 33·7	11 33·6
	E.S.E.	11 40·8	
	S.S.E.	11 26·2	
South to West	S. by W.	11 29·7	11 33·7
	S.W.	11 33·3	
	W. by S.	11 36·2	
West to North	W. by N.	11 31·1	11 35·5
	W.N.W.	11 34·5	
	N.W.	11 39·5	
	N. by W.	11 36·8	

On shore, at Keemah, the mean of five observations by Fox's Dip Circle was 11° 28′·0, and as the Schooner bore E.S.E. the correction for distance would be − 1′; the dip by this instrument at the ship would be − 11° 29′, and the correction, therefore, for the direction of the ship's head and of local attraction, is, from north to east + 8′·2; east to south + 4′·6; south to west + 4′·7; west to north + 6′·5.

Index Correction.

True dip on shore from nine needles . . .	11° 02′·7
Dip from needle B. (Fox) as above	11° 28′·0
Index correction	+25·3

This instrument Colonel Sabine, R.A. had the kindness to send out to me, and I used it whenever an opportunity offered, but the Schooner was so small that it was difficult to take observations of inclination when there was any sea on. The needle B. was never removed from the box, and advantage was taken at every station of applying to the dip a fresh index correction. Fox's Dip Circle, sent out overland, was very roughly handled on its way out, so that the circle was no longer concentric to the axis of the needle. The observations were taken on a gymbal stand, the dip circle being leveled as accurately as possible, and twenty readings taken with the face of the circle to the east, and the same number with the face of the circle to the west. The inclinations at sea contained in the General Table, are the means of several groups of observations; for the dip being observed whenever it was calm, three or even five observations were taken repeatedly during the day when the weather permitted.

General Table, and Reduction of Observations to one common Epoch.

The General Table of Inclination on shore and at sea is given at pages cxxxvii, cxxxviii and cxxxix. The whole of the observations are reduced to one common epoch, viz. the 1st of January, 1848. At the Singapore Observatory observations were taken at two different periods, and with great care.

At the commencement of 1848 the dip was	−12° 56′·8
At the commencement of 1849 the dip was	−12° 59′·4
The difference nearly, of one year . . .	= −2′·6

These are valuable chiefly from the superior character of the instruments and dipping-needles. But going back to the first establishment of the observatory, the mean dip of the needle was—

At the end of 1841	−12° 43′·3
At the end of 1848, or commencement of 1849 . .	−12° 59′·4
	−16′·1

giving for the yearly change −2′·3.

The secular change at Madras can likewise be determined; for from the mean of twenty-two observations taken in July 1840,

The mean dip of the needle was	+7° 13′ 40″ N.
Twenty-nine observations in July and August 1849, gave	+7° 37′ 42″
Total difference in nine years	+24′ 02″

being 2′·7 per annum increase, or 0′·22 per mensem. This rate of 0′·22 per mensem is assumed as the correction to be added to observations taken prior to January 1848 to correct them to that epoch, and subtracted from observations taken subsequent to that date. This change at Madras is I believe strictly in accordance with the observations of Captain Ludlow of the Madras Engineers, the talented director of the magnetic establishment at that station. As the south end of the needle dips at Singapore and the north end at Madras, and the inclination is increasing at both stations, there must be at some intermediate spot a point of contrary flexure.

The method of observing on shore after the reception of the three new dip circles was never altered with those needles whose poles were changed; the circle being always in the magnetic meridian; two sets of readings were taken in each position of the needle, the usual eight positions being observed for the correction of instrumental error as follows: viz. needle direct and reversed for the non-coincidence of the magnetic axis with the axis of form; the circle east and the circle west for the correction of the zero of the vertical limb, and the same four positions with the poles changed to correct the error arising from the centre of gravity not coinciding exactly with the axle of the needle.

With a view of ascertaining the value of the observations of the inclination, I drew up the following Table of the probable error of a single determination, and of the probable error of the mean value of the inclination at some of the principal points of the Eastern Archipelago.

The first column contains the year and month; the second, the name of the station; the third, the number of needles; the fourth, the number of dip circles observed; the fifth, the number of observations; the sixth, the mean value of the dip; the seventh, the probable error of a single determination; and the eighth, the probable error of the mean value.

Year and Month.	Name of Station.		No. of Needles.	No. of Dip Circles.	No. of observations.	Mean value of the Dip.	Probable error of a single determination.	Probable error of the mean value.
March, 1846	Singapore		3	1	21	−12 47·7	±′4·3	±′0·9
July, 1846	Sambas	Borneo	3	1	6	14 26·5	4·2	1·7
	Pantiānak		3	1	9	14 41·0	3·3	1·1
May and June	Sarāwak		3	1	27	11 09·7	4·9	0·9
September, 1846	Batavia	Java.	3	1	9	27 03·7	3·1	1·0
November			6	3	6	27 02·4	2·0	0·8
November	Tegu		12	3	19	28 42·5	1·8	0·4
November	Top of Gedé		5	2	6	29 42·7	1·8	0·7
December	Chunjūr		12	3	12	28 23·1	2·4	0·7
December	Sidang Bārang		4	1	8	30 12·1	1·3	0·4
December	Bandong		11	3	15	28 31·1	2·9	0·8
December	Garoet		6	2	6	28 58·5	0·7	0·3
December	Permangpek		4	1	8	30 11·8	0·9	0·3
February, 1847	Soorabāya		4	1	8	28 50·2	3·8	1·3
March, 1847	Sūmenap		4	1	12	27 43·5	1·3	0·4
April	PuloKuneeang		4	1	12	27 23·6	2·3	0·7
May	Kedeeri		4	1	12	29 50·0	2·1	0·6
July	Batavia		9	3	44	27 08·2	1·8	0·3
September	Bencoolen		9	3	17	23 53·1	1·9	0·5
October	Padang		9	3	9	18 31·7	3·9	1·3
February, 1848	Singapore, A.M.		4	1	28	12 56·4	2·0	0·4
	P.M.		4	1	28	12 57·2	1·9	0·4
			4	1	56	12 56·8	2·0	0·3
May	Pulo Labooan		9	3	9	2 53·2	1·7	0·6
	Sambooanga		9	3	9	+ 1 19·3	1·6	0·5
June	Keemah		9	3	9	−11 02·7	1·7	0·4
August	Cocos		9	3	36	39 20	1·3	0·2
November	Singapore		9	3	80	12 59·4	2·8	1·3
January, 1849	Malacca		9	3	9	11 27·9	0·9	0·3
January	Pulo Dinding		9	3	9	7 33·9	2·2	0·7
January	Penang		9	3	9	4 55·5	1·6	0·4
February	Nicobar		9	3	9	+ 1 17·8	1·1	0·4
March	Hastings' Island		9	3	9	4 32·3	1·9	0·6
April	Moulmein		8	3	8	17 49·1	2·5	0·9
July	Madras		9	3	29	7 37·7	1·5	0·3

Horizontal Intensity.

The horizontal intensity was determined from four declinometers, viz. the small Observatory Declinometer at Singapore; the Induction or No. II; Jones's or No. III; and the Portable Declinometer.

The Observatory Declinometer with apparatus, consisted of a small gun-metal box, in which was suspended a needle 3 inches in length with mirror attached: two deflecting bars at right angles to the box, were marked off to 0·05 of a foot. A telescope and scale detached from the instrument, and put on a separate pillar, completed the apparatus, which was placed in a building near the magnetic observatory.

2nd. *The Induction or No.* II. *Declinometer.*—This instrument has already been described; the apparatus for deflection consists of two arms fixed at right angles to the box; they were of insufficient length, as the greatest distance at which the deflecting magnet could be placed was 1·4 foot. On measuring the angles of deflection, the ivory scale was always made use of instead of the horizontal limb of the instrument; and the advantage gained by this was rapidity of observation.

Jones's, or No. III Declinometer, was received at the termination of the Survey; it was liable to derangement from the difficulty of clamping the limb securely; in other respects the instrument was a very great improvement upon No. II. Declinometer; the ivory scale had a greater range; the deflecting bar at right angles to the instrument was a strong brass scale, supporting a moveable stirrup on its upper edge, on which the deflecting magnet was placed, so that it could be moved backwards and forwards by sliding the stirrup along the scale: the great advantage of this arrangement consisted in the deflecting magnet never being touched, nor affected by the heat of the hand.

Six deflecting needles were used with the three declinometers, D 5, D 6, A 7, A 8, A 9 and A 10. D 6 was lost at Padang in Sumātra.

The Portable or No. IV. Declinometer, was used both for variation and for horizontal intensity; so that after altitudes of the sun and the magnetic axis of the collimator magnet had been observed, the instrument became available for observations of deflection and vibration; C 15 a collimator magnet, being suspended, and C 7 the deflecting needle. The angles of deflection were read off on the glass scale of the suspended magnet, the divisions of which were very coarsely cut.

Explanation of Table G.

The observations are contained in Table G. from page cxl to page cliii. The results are given in eleven columns. The first contains the date; the second, the station; the third and fourth, the suspended and deflecting magnets; the fifth and sixth, the distances at which the magnets were placed, with the corresponding angles of deflection; the seventh, the observed time of 300 vibrations; the eighth, the Declinometer; O standing for the Observatory, I for the Induction, J for Jones's, and P for the Portable Declinometer; the ninth and tenth, the values of m and X, m being the moment of free magnetism of the deflecting bar, and X the horizontal component of the earth's magnetic force; and the eleventh, the mean value of X.

Mode of Observation in determining the Horizontal Component of the Force.

The position of the deflected magnet was read off without the deflecting magnet, both at the commencement and at the end of the observations, and the change which had occurred in the declination in the interval was thus shown without the necessity of a subsidiary instrument. The change of declination observed was spread over the observations, on the supposition that it had been uniform. The deflecting magnet was placed on the brass scale to the west of the declinometer, and moved successively to four or eight distances, with the marked end of the needle to the west and to the east. The needle was then placed to the east of the deflected magnet, and a similar operation performed. This concluded the experiments of deflection.

To determine the time of one vibration, 360 were observed, and care was taken that the vibrations of the deflecting needle should be limited to an exceedingly small arc.

Formulæ for the Determination of m and X.

Deflection.—The value of $\frac{m}{X}$ is found for each distance by the formula

$$\frac{m}{X}=\frac{1}{2}r^3 \tan a \, . \frac{1}{1+\frac{P}{r^2}},$$

where

$$P=-\frac{r^2 r_\prime^5 \tan a_\prime - r_\prime^2 r^5 \tan a}{r_\prime^5 \tan a_\prime - r^5 \tan a},$$

r and $r_\prime$ being two distances at which the deflecting magnet is placed, a and $a_\prime$ the corresponding angles of deflection.

Vibration.—From the experiments of vibration,

$$mX=\frac{\pi^2 k}{T^2},$$

where π is the ratio of the circumference of a circle to its diameter, k the moment of inertia of the magnet and stirrup, T the time of one vibration.

To obtain the value of k, a cylindrical brass weight is attached at each end of the magnet,

and

$$k=k_\prime \frac{T^2}{T'^2-T^2}$$

where $k_\prime$ is the moment of inertia of the magnet and attached weights, T the time of vibration with the magnet and stirrup only, T′ the time with the weights attached,

and

$$k_\prime=\left(\frac{1}{2}l^2+r^2\right)p\,;$$

in which l=the interval between the points of suspension of the weights, r the radius of the brass cylinders, and $2p$ their weight.

Determination of the Coefficients.

In finding the values of m and X, it is necessary to determine certain constants; such as (1) the value of one division of the scale of the suspended magnet; (2) the coefficient of temperature of the deflecting magnet; (3) its moment of inertia; (4) the value of P.

(1.) *Value of one division of the scale.*—In the Singapore Observatory Declinometer, the value of one scale division was determined by the formula

$$d'=\frac{l}{2r}\times 3437'\cdot747:$$

the results alone are given.

November 22, 1845.—Value of one scale division . . . . . . =1′·002

$1+\frac{\text{H}(=\text{torsion force})}{\text{F}\ (=\text{magnetic directive force})}$ . . =1·0004

March 21, 1846.—Value of one scale division . . . =59″·983=1′ nearly,

$1+\frac{\text{H}}{\text{F}}$ . . . . =1·0004

March 7, 1848.—Value of one scale division . . . . =1′·0081

$1+\frac{\text{H}}{\text{F}}$ . . . . =1·0007

On returning to the observatory, in December 1848, after an absence of several months, I found that the pillar supporting the instrument was slightly inclined, the foundation having been undermined, probably by white ants; I rebuilt the pillar, and the instrument being readjusted, the value of one scale division=1′·0005.

The value of one scale division of the Induction Inclinometer has been already stated=1′·0.

The value of one division of No. III. Declinometer was determined at Samboo-anga, May 31, 1848.

By measuring the scale, with the aid of the horizontal circle, the value of one scale division has been ascertained. . . . . . . =1′·0036

and $1+\frac{\text{H}}{\text{F}}$ . . . =1·00037

The value of one division of C 15, the suspended collimator magnet of the Portable Declinometer, was determined from time to time; but the following are the results with two theodolites.

By the large altitude and azimuth, value of one scale division . =2′·904
By the small theodolite . . . . =2·900
Mean value . . . . 2·902

The value of one scale division of C 7 the deflecting collimator magnet, was found to be =2′·342.

(2.) *Coefficient of Temperature.*—The coefficient of temperature, or value of q, was determined by vibrating the needles in an oak box, and increasing the temperature of the room in which the magnets were vibrated. Perhaps the coefficient of temperature has not been sufficiently well determined; but as the standard temperature to which the magnets are reduced is 80°, and the temperature of the deflecting magnets never differed materially from this, a slight error in the determination of the coefficient would make no perceptible difference in the resulting value of X.

Experiments were carried on at Woolwich, at the end of last year, with one of the needles; the coefficient of temperature was determined for the cylindrical magnet

D 5 by the method of deflection, and the result coincided with the value of q found by vibration.

The following Table contains the determination of the value of q, or of the coefficient of temperature of the small magnets.

$q=\frac{T'-T}{T(t'-t)}$, in which t' and t are the two temperatures, and T' and T the corresponding times of vibration.

Date.	No. of magnet.	No. of vibrations.	T.	t.	No. of vibrations.	T′.	t'.	$t'-t$.	T′−T.	Value of q.	
1844.											
June 7.	D 5	720	86·5	341″·635	3600	121·3	343″·05	34°·8	1″·415	·000119	Mean of the solid magnets $q=·000105$.
May 28.	D 6	1080	86·6	339·47	1440	116·8	340·252	30·22	0·7825	·000076	
	A 7	720	86·25	254·725	720	118·3	256	32	1·275	·0001565	
May 30.	A 8	720	86·5	315·08	1080	119	316·33	32·5	1 25	·000122	Mean of the hollow cylindrical magnets $q=·000322$.
May 30.	A 10	720	87	266·755	1080	120	267·637	33	0·882	·0001	
June 7.	H 9	360	87	180 3	360	113·8	182	26·8	1·7	·000352	
June 14.	H 10	360	86·8	181·92	720	126	183·805	29·2	1·885	·000355	
June 27.	H 11	360	87	172·96	360	103	173·66	16·0	0·701	·000253	
1845.											
April 7.	C 7	756	88·5	423·1	360	109·7	427·00	21·2	2·28	·00025	

(3.) *Moment of Inertia.*—The moment of inertia was determined at different periods. The following Table contains the moments of inertia prior to the commencement of the Survey at the Singapore Magnetic Observatory.

Date.	Magnet.	Small weights.		Length of magnet in feet.	p, or weight of cylinder in grs.	r, or radius of cylinder in feet.	Moment of inertia $k_{,}=\frac{1}{2}l^2p+r^2$ $k=k_{,}\frac{t^2}{t'^2-t^2}$.	Large weights.		p, or weight of cylinder in grs.	r, or radius of cylinder in feet.	Moment of inertia $k_{,}=\frac{1}{2}l^2p+r^2$ $k=k_{,}\frac{t^2}{t_{,}^2-t^2}$.	Radius of magnet in feet, or $r_{,}$.	Weight of magnet in grs., or $p_{,}$.	Moment of inertia $k_{,}=\frac{1}{12}l^2p_{,}+\frac{1}{4}r_{,}^2p_{,}$.
		Time of 1 vibration from 360. Needle loaded, t'.	Time of 1 vibration from 360. Needle unloaded, t.					Time of 1 vibration from 360. Needle loaded, t'.	Time of 1 vibration from 360. Needle unloaded, t.						
1845.															
March 7.	D 5	6″·9316	3″·7	·3033	210	·01335	3·863	9″·0289	3″·7	414	·01675	3·862	·0125	497	3·8294
May 1.	......	6·9678	3·7202	......	......	......	3·865	9·0379	3·7202	......	......	3·862			
March 15.	D 6	7 025	3·7266	......	......	......	3·7972	9·1661	3·7266	......	......	3·7934	......	490	3·7751
May 2.	......	7·0221	3·7249	......	......	......	3·7931	9·1526	3·7249	......	......	3·7995			
1844.															
August ...	......	6·7881	3·6097	......	......	......	3·8236	8·87276	3·6097	......	......	3·798			
	......	6·7964	3·6082	......	......	......	3·8056	8·8728	8·6082	......	......	3·7955			
	......	6·7933	3·607	......	......	......	3·8158	8·877	3·607	......	......	3·7882			
March 17.	A 5	5·355	2·6958	·2522	......	......	2·2798	7·0458	2·6958	......	......	2·2779	......	418	2·232
1845.															
March 18.	A 6	6·1154	3 0733	......	......	......	2·2693	8·0533	3·0733	......	......	2·2641	......	416·5	2·224
19.	A 7	5·4478	2·74	......	......	......	2·2742	7·18	2·74	......	......	2·2641	......	416·5	2·224
22.	A 8	6·5843	3·2933	......	......	......	2·2408	8·2758	3·2933	......	......	2·2366	......	411·5	2·197
24.	A 9	5·657	2·81	......	......	......	2·1998	7·4661	2·81	......	......	2·1920	......	405·5	2·165
25.	A 10	5·7172	2·8664	......	......	......	2·2551	7 5372	2·8664	......	......	2·2158	......	415	2·216
26.	C 7	5·7533	4·4194	·3350	......	......	17·014	6·8027	4·4194	......	......	17·191			

The following Table contains the results of the values of π^2k found for each needle; the mean value of π^2k determined from observations prior to 1847 being considered as of value equal to those taken subsequently.

Date and Station.	Value of π^2k for the cylindrical magnets and the collimator magnet.					
	D 5.	A 7.	A 8.	A 9.	A 10.	C 7.
Singapore, prior to 1847	38·225	22·485	22·281	21·818	22·394	168·14
Batavia, July, 1847	38·265	22·443	22·140	21·882	22·363	167·30
Singapore, February, 1848	38·482	22·353	22·124	21·797	22·385	166·94
Singapore, December, 1848	38·423	22·296	22·126	21·783	22·307	167·25
Madras, September, 1849	38·208	22·884	21·846	21·813	22·383	

The mean value of $\pi^2 k$ has been employed in determining the value of X; that is to say, the value of $\pi^2 k$ found at a station is added to the results determined at previous periods, and a mean assumed as the true value of $\pi^2 k$.

(4.) *Value of* $P = -\frac{r^2 r_{\prime}^5 \tan a_{\prime} - r_{\prime}^2 r^5 \tan a}{r_{\prime}^5 \tan a_{\prime} - r^5 \tan a}$.—The value of P was determined for each needle, from the mean of many angles of deflection at the same distances. The following are the results of the mean value of P for the different magnets and the four declinometers.

March, 1846, at Singapore, the value of P for D 5 and D 6, determined by the Observatory Declinometer, was −·00309.

June, 1846, at Sarāwak, by the Induction Inclinometer,—

The value of P for D 5 was	+·00320
D 6	+·00169
A 6	−·024157
A 7	−·007276
A 8	−·00726
A 9	−·00335
A 10	−·00335
C 7	−·00361

June, 1848, at Sambooanga, in the island of Mindanão, by No. III. Declinometer,—

The value of P for D 5 was	−·00148
A 7	−·01642
A 8	−·00900
A 9	−·01218
A 10	−·01407

December, 1848, at Singapore, by No. III. Declinometer, the value of P for

A 8 was . .	−·00930
A 9 was . .	−·01059
A 10 was . .	−·00932

and by the Observatory Declinometer the value of P for A 8 was −·00751.

Remarks.—The observations of deflection are exceedingly numerous, and it is to be regretted that some of the time expended on them was not bestowed on the more complete determination of the coefficients; but, as the angles of deflection were exceedingly small, it was deemed advisable to multiply observations for the value of $\frac{m}{X}$ as much as practicable. The needle was not always vibrated on the same day on which the experiments of deflection were observed, yet care was taken that it should be vibrated at the same time at which the deflection was observed; and in low latitudes, subject to trifling disturbances, there is a greater change in a few hours on the same day, than there will be after the lapse of some time at the same hours; thus there would be a much greater difference in the time of vibration of a needle at 11 A.M. and 5 P.M. on the same day, than if it were vibrated at 11 A.M. on different days.

The following Table contains the probable error of a single determination, and also of the mean value of the horizontal intensity, at each station in the Eastern Archipelago.

Year and Month.	Name of Station.	No. of observations.	Number of deflecting needles.	Number of instruments.	Mean value of the horizontal intensity.	Probable error	
						Of a single determination.	Of the mean value.
1845	Singapore	179	2	2	8·095	±·009	±·0007
March, 1846	Singapore	55	7	2	8·121	·0095	·0013
March, 1848	Singapore	199	5	2	8·116	·0090	·0006
December	Singapore	300	5	3	8·114	·0103	·0006
January, 1846	Pulo Peesang	18	7	1	8·092	·0070	·0017
January	Carimons	15	6	1	8·077	·0090	·0056
February	Lingin	16	6	1	8·062	·0070	·0017
June	Sarāwak	43	7	1	8·186	·007	·001
September	Batavia	56	7	1	7·894	·010	·0014
July, 1847	Batavia	218	6	1	7·891	·0084	·0006
August	Lampongs, Sumātra	24	6	1	7·916	·0070	·0014
September	Bencoolen	24	6	1	7·913	·0053	·0011
October	Padang	24	6	1	7·962	·011	·002
March, 1848	Ophir, near Malacca	20	5	1	8·255	·017	·0038
May	Pulo Labooan	20	5	1	8·240	·0052	·0012
May	Sambooanga	60	5	2	8·162	·0110	·0015
June	Keemah	60	5	2	8·253	·0120	·0015
August	Cocos	120	5	2	7·274	·010	·0009
February, 1849	Nicobar	60	5	2	8·155	·011	·0014
January	Pulo Dinding	20	5	1	8·117	·006	·0014
January	Pulo Penang	20	5	1	8·159	·007	·0015
March	Hastings' Island	20	5	1	8·177	·007	·0015
April	Moulmein	59	5	2	8·119	·0085	·0011
August	Madras	127	5	2	8·078	·0085	·0007

Table H.

Table H, at pages cliv and clv, contains the absolute determinations of Total Force, and of the Horizontal Component, of Inclination and of Variation.

Explanation of Table H.—The first five columns require no explanation. The sixth column contains the horizontal intensity deduced from observations made with the four declinometers; the values of the horizontal intensity given by the portable declinometer, are less than those found by means of the other three declinometers; this has arisen from the shrinking of the oak deflecting bar of the portable declinometer, by which the values of r, r', &c., the distances of the deflecting from the suspended magnet, are less than they should be, consequently the angles of deflection are greater than they ought to be; $\frac{m}{X}$ is therefore greater and X less than its true value; but this shrinking must have happened before the Survey; for the ratio of the true horizontal intensity deduced from the three declinometers, to the horizontal intensity found by means of the portable declinometer, is constant.

As the instrument was left at Madras, I have no means of measuring the true values of *r*, *r*′, &c.; but if four stations be taken, Singapore at the commencement, Batavia and the Cocos during the Survey, and Madras at its termination, we find the comparison to be as follows:—

	Horizontal intensity from three declinometers.	Horizontal intensity from portable declinometer.	Ratio.
Singapore, 1845	8·0947	7·9495	1·0182
Singapore, 1846	8·121	7·951	1·0214
Singapore, 1848	8·114	7·991	1·0154
Batavia, 1847	7·897	7·784	1·0145
Cocos, 1848	7·2745	7·167	1·0150
Madras, 1849	8·0784	7·951	1·0160
		Mean ratio . . .	1·0167

by which ratio 1·0167, all the values of the horizontal intensity found by means of the portable declinometer, are multiplied for the true value.

The seventh column contains the total intensity. The total intensity has not been determined by direct observation, but from the formula $h=f\cos\delta$,

or

$$f=\frac{h}{\cos\delta}=h\,.\sec\delta,$$

where h is the horizontal intensity,

δ the dip,

and f the total intensity.

The eighth column contains the variation or magnetic declination, found by means of the altitude and azimuth instrument and collimator magnet. The following Table is given in explanation of the manner in which the variation was determined, the station being on Direction Island at the Cocos; each observation is the mean of three sets of altitudes and azimuths, with the vertical limb in the direct and reversed positions.

Date.	Time.	Reading of the true meridian on the limb.								Mean of the two sets, or true meridian on the limb.	Mean of magnetic axis on the limb.	Mean magnetic variation.
		Limb direct.				Limb reversed on its axis.						
		1.	2.	3.	Mean.	1.	2.	3.	Mean.			
												West. ° ′ ″
Aug. 28.	A.M.	211 18 30	211 17 10	211 18 00	211 17 53	211 34 10	211 34 40	211 34 00	211 34 17	211 26 05	210 16 28	1 09 37
29.	A.M.	211 29 47	211 29 27	211 30 17	211 29 50	211 32 23	211 30 13	211 32 57	211 31 51	211 30 50	210 18 06	1 12 44*
31.	A.M.	211 27 40	211 26 50	211 27 10	211 27 13	211 26 00	211 25 04	211 25 00	211 25 21	211 26 17	210 16 16	1 10 01
Sept. 7.	A.M.	211 23 53	211 23 23	211 25 27	211 24 14	211 30 07	211 29 53	211 29 53	211 29 58	211 27 06	210 17 06	1 10 00
9.	A.M.	211 25 30	211 25 16	211 26 20	211 25 42	211 29 40	211 27 30	211 28 03	211 28 24	211 27 03	210 17 20	1 09 43
19.	A.M.	211 28 05	211 28 14	211 30 54	211 29 04	211 23 40	211 25 40	211 23 59	211 24 26	211 26 45	210 18 37	1 08 08
27.	A.M.	212 10 17	212 10 40	212 12 44	212 11 14	212 08 30	212 07 40	212 09 47	212 08 39	212 09 50	210 55 18	1 14 38†
								Mean of the variation				1 10 42

* New spider's web, and instrument readjusted.

† New level put on the vertical limb, and position of the altitude and azimuth changed.

The eleventh column contains the altitudes of the stations above the sea level. Unfortunately, during the survey of Java, I had no barometer with me.

Table I.

Table I contains the observations made at sea; the inclination determined by Fox's Dip Circle have already been noticed. The meteorological observations, consisting of the temperature of the air and of the sea, were taken when practicable, at 15, 18, and 21 hours, at noon, and at 3, 6, and 9 P.M. The observations of the temperature of the sea were made in the following manner:—the thermometer was placed in a bucket of sea-water, allowed to stand for a few minutes whilst the other instruments were observed, and the thermometer was read off whilst its bulb was still immersed.

The Table contained at pages clvi and clvii requires no explanation.

On the Direction of the Isoclinal and Isodynamic Lines, and the Lines of Equal Variation or Magnetic Declination.

On the Isoclinal Lines.—The observations of dip or inclination have been combined for the position of the isoclinal lines, their mean direction, and their mean distance apart; they have been formed into four different groups.

1st Group.—Singapore, Borneo, and Java, afford forty stations; and if we call δ the dip at the central position, u the angle which the isoclinal line passing through the central position makes with the meridian, and r a constant coefficient, which determines the rate of increase in a direction perpendicular to the isoclinal line; and we put

$$r \cos u = x$$
$$r \sin u = y,$$

we may make equations of condition of the following form:

$$ax + by = \delta - \delta',$$

where a and b are coordinates of distance in longitude and latitude of the several stations from the mean, expressed in geographical miles; δ' the inclination at these several stations, and δ the mean dip.

Then from this group we obtain, the results alone being given,

At a mean latitude . = 6° 17′ South.
Mean longitude = 108 55 East.
And mean dip . . = − 27 01·5 South.

$$x = -0{\cdot}132 \qquad y = +1{\cdot}935$$
$$r = +1'{\cdot}940 \text{ and } u = -86^\circ\ 06'.$$

The axes of coordinates are throughout assumed positive when taken to the north and west; so that as we proceed to the north, the dip increases at the rate of 1′·940 perpendicular to the isoclinal line which forms an angle of N. 86° 06′ E. to S. 86° 06′ West.

2nd Group.—Sumātra contains thirty stations; the resulting equations give—

At a mean latitude . = 0° 08′ South.
At a mean longitude . = 100 31 East.
And mean dip . . = 16 36′·6 South.
$x=+0{\cdot}230$; $y=+2{\cdot}008$
$r=+2'{\cdot}021$ and $u=83^\circ\ 28'$.

We have therefore, the isoclinal line in Sumātra forming an angle of N. 83° 28′ W. to S. 83° 28′ East, and the line at right angles to it increasing at the rate of 2′·021; and as the central station, through which this line passes, is only 8 miles to the south of the equator, we may assume this to be the rate at which the dip increases at nearly right angles to the terrestrial equator in longitude 100° 31′ East.

3rd Group.—From the third group we have thirty observations taken at sea. The resulting equations give—

At a mean latitude . = 2° 38′ North.
At a mean longitude = 110 05 East.
And mean dip . . . = 9 11·7 South.
$x=+0{\cdot}089$; $y=+1{\cdot}991$
$u=87^\circ\ 26'$; $r=+1'{\cdot}993$.

We have, therefore, the isoclinal line running N. 87° 26′ W. to S. 87° 26′ East, and the line at right angles increasing at the rate of +1′·993 for each geographical mile.

4th Group.—In the fourth group are contained the principal stations in the Magnetic Survey, extending from the 80th to the 125th degree of east longitude, and from 16½° North to 12° South.

From the resulting equations we obtain—

At a mean latitude . = 0° 09′ North.
At a mean longitude = 104 44 East.
And mean dip . . = 14 40·4 South.
$x=+0{\cdot}114$ $y=+1'{\cdot}947$
$u=86^\circ\ 39'$; $r=+1'{\cdot}953$.

The isoclinal line runs therefore N. 86° 39′ W. to S. 86° 39′ East, and the line at right angles to it increases at the rate of 1′·953 for each geographical mile.

On the Lines of Equal Horizontal Intensity.

For the lines of equal horizontal intensity the equations of condition have been combined in the same manner by the method of least squares.

From one group of forty stations

At a mean latitude of . . . . 0° 38′·5 North.
At a mean longitude of . . . . 102 26 East.
$x=+{\cdot}000312076$; $y=+{\cdot}000765277$
$r=+{\cdot}0008249$; $u=67^\circ\ 48'$.

The line of equal horizontal intensity forms an angle of N. 67° 48′ W. to S. 67° 48′ E. with the meridian, and on the line perpendicular to this the horizontal intensity increases at the rate of ·0008249 the geographical mile.

From a second group of seventy-seven stations, comprising all those at some distance to the south of the line of maximum horizontal intensity, we obtain

At a mean latitude . . . . . = $\overset{\circ}{3}$ $\overset{\prime}{40}$ South.
At a mean longitude . . . . =106 33·0 East.

$$x=+\cdot00028453\,;\quad y=+\cdot0005117$$
$$u=60^\circ\,57'\,;\quad r=+\cdot000585439.$$

The line of equal horizontal intensity forms an angle of N. 60° 57′ W. to S. 60° 57′ E. with the meridian, and the horizontal intensity on a line perpendicular to this increases at the rate of ·0005855 the geographical mile.

Lines of Total Intensity.

The total intensity has been determined by the formula $h=f\cos\delta$,

or $$f=\frac{h}{\cos\delta}=h\sec\delta,$$

where h is the horizontal intensity,
δ the dip,
f the total intensity;

eighty equations of condition of the following form,

$$ax+by=f-f',$$

have been combined by the method of least squares, so as to assume the form of the two following equations:—

$$a^2x+aby=a(f-f')$$
$$abx+b^2y=b(f-f'),$$

a and b being the coordinates of distance in longitude and latitude from the mean station for any station, and f' its intensity; f the mean total intensity $=8{\cdot}745$.

Then by adding together the equations of condition for each station, we obtain the following:—

$$r=-\cdot001073,$$
$$u=85^\circ\,36',$$

at a mean latitude of 3° 05′ S. and a mean longitude of 106° 47′ E.

The angle which the line of equal total intensity forms with the meridian is N. 85° 36′ W. to S. 85° 36′ E., and increases southerly at the rate of ·001073 the geographical mile. The line of least intensity in that part of the Archipelago over which I have carried the Survey, agrees nearly with the line of no dip. On looking over the list of stations, we find Sambooanga, Nicobar, and Madras, with the least total intensity. Sambooanga and Nicobar are about forty miles north of the line of no dip. The angle which the line of least intensity makes with the meridian is nearly a right angle.

Lines of Variation.

The first attempt which I made to determine the lines of equal variation was unsatisfactory. From 120 equations of condition combined by the method of least squares, I obtained results quite at variance with the actual fact.

I then broke up the observations into three groups, one to the extreme west, comprising the observations taken in Sumātra, one in the centre comprising the observations taken in Java, and the third group to the east. The results thus obtained are more satisfactory, for the line of equal variation in the longitudes and latitudes over which the Survey extended is a straight line for a very short distance only.

1st, or Eastern group:—

At a mean latitude. . . . . = 2° 03′ North.
At a mean longitude . . . . =113 53 East.
And mean variation . . . . = 1 23 East.

The line of equal variation forms an angle of N. 52° 51′ E. to S. 52° 51′ W. with the meridian, and the rate of progression, or the value of r, is $-0'\cdot0346$ the geographical mile.

2nd, or Sumātra group:—

At a mean latitude. . . . . = 1° 36′ North.
At a mean longitude . . . . =100 36 East.
At a mean variation . . . . = 1 35 East.

$$u=-82^\circ\ 06',$$

$$\text{and } r=+\cdot0545\,;$$

so that the variation increases as we proceed northerly, at the rate of $+\cdot0545$ the geographical mile; the line of equal variation forming an angle of N. 82° 06′ E. to S. 82° 06′ W.

3rd, or Java group:—

At a mean latitude. . . . . = 7° 03′ South.
At a mean longitude . . . . =108 51 East.
At a mean variation . . . . =+0 35 East.

The value of $r=0'\cdot145$.
The value of $u=-89^\circ\ 24'$,

so that the line of equal variation in Java forms with the meridian an angle of N. 89° 24′ E., and proceeds at the rate of $0'\cdot145$ the geographical mile.

The lines have been laid down on the charts nearly in accordance with the foregoing results.

The line of equal inclination forms an angle of 86° 40′ with the meridian, and changes in a direction perpendicular to it at the rate of 1′·970 the geographical mile.

The line of equal horizontal intensity forms an angle of nearly 65° with the meridian. For the position of the central line of maximum horizontal intensity, I have taken stations north and south of this line having the same horizontal intensity, and have divided the distance between them; and in laying down the rate of decrease of the horizontal intensity, I have fixed upon the Java group, which has the greatest number of stations, as decreasing at the rate given me by the equations of condition; but since the horizontal intensity at the Cocos shows a much more rapid decrease when at some distance from the line of maximum horizontal intensity, I have gradually increased the rate of progression to the Cocos, and decreased it in the same proportion northwards from Java to the line of maximum horizontal intensity.

The lines of total intensity are laid down in strict conformity with the resulting equations of condition. The direction of the lines is between 85° and 86°, and proceeds at the rate of ·001073 the geographical mile. There is much less difficulty in laying down the total intensity lines than the lines of horizontal intensity; for the former, and the rate of progression in a direction normal to them, are functions of the dip and horizontal intensity; and since the dip changes very rapidly, whilst the horizontal intensity is nearly stationary in the immediate vicinity of the maximum horizontal intensity, it follows, first, that the line of minimum total intensity will coincide nearly with the line of no dip; and secondly, that its rate of progression, or the value of r, will be as uniform and as constant as the lines of dip, for it has been shown that over the space of 28° of latitude over which this Survey extends, the dip changes at the rate of nearly two miles for every mile of latitude.

In laying down the lines of variation, I have been guided partly by the equations of condition, but to be directed by these alone would lead to very unsatisfactory results. I have, in the Java group and in the Eastern group, conformed to the results of the equations of condition combined by the method of least squares, whilst in the western group I have simply connected together by lines the stations having the same variation.

Explanation of Plates XII. *and* XIII.

Plate XII. contains the isoclinal lines or lines of equal magnetic dip and lines of equal magnetic declination, as well as the central lines of minimum total intensity and of maximum horizontal intensity.

Plate XIII. contains the isodynamic lines or lines of equal horizontal intensity and of equal total intensity; and in addition, the line of no magnetic declination and the line of no dip.

Pimlico Lodge, Westminster,
November 15, 1850.

ERRATA.

Page ii, line 1, *omit* Moulmein.

—— iv, line 18, at 21 hours, *for* 1·1 *read* 0·1.

—— iv, line 22, at 21 hours, *for* 2·1 *read* 1·1.

—— iv, line 23, at 21 hours, *for* 0·52 *read* 0·27.

—— iv, line 24, in the line of Oscillation, *for* 1·33, 1·28, &c., and

—— ii, line 15, in the line of Batavia, Spring, *for* 1·33, 1·28, &c. *read*
1·48, 1·43, 1·38, 1·55, 1·40, 0·58, 0·00, 0·15, 0·38, 0·80, 1·28, 1·78, 2·21, 2·25, 1·95, 1·60, 1·35, 1·08, 0·73……1·25.

—— vi, line 11, at 21 hours, *for* 1·2 *read* 0·2.

—— vi, line 15, at 21 hours, *for* 1·9 *read* 0·9.

—— vi, line 16, at 21 hours, *for* 0·47 *read* 0·22.

—— vi, line 17, in the line of Oscillation, *for* 1·50, 1·46, &c., and

—— ii, line 32, in the line of Batavia, Spring, *for* 1·50, 1·46, &c. *read*
1·60, 1·56, 1·40, 1·50, 1·38, 0·48, 0·00, 0·10, 0·60, 1·23, 1·93, 2·58, 3·13, 3·28, 3·06, 2·60, 2·36, 1·98, 1·50……1·68.

—— x and xi, line 1, *for* the sign (′) *read* scale divisions.

—— xl, last line but one at 21 hours, *for* 1·1 *read* 0·1.

Abstracts and Tables of the Magnetic and Meteorological Instruments at Sixteen Stations in the Indian Archipelago.

Oscillation of the Declination at various Stations

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Moulmein.	′	′	′	′	′	′	′	′	′	′	′
Madras	......	......	......	1·85	1·87	1·94	2·59	3·75	4·12	3·11	2·02
Nicobar	......	......	......	1·68	1·44	0·92	0·18	0·00	0·42	2·02	3·38
Sambooanga	......	......	......	3·01	3·06	3·10	3·58	3·91	3·28	2·01	0·85
Penang	......	......	......	2·02	2·00	1·64	0·66	0·00	0·70	2·34	4·00
Pulo Dinding	......	......	......	3·70	3·37	3·07	2·40	0·67	0·00	1·53	4·20
Sarawak	1·00	1·13	1·34	1·54	1·67	1·84	2·41	3·22	2·67	1·56	0·92
Keemah	......	......	......	3·26	3·11	3·31	3·33	4·56	3·88	2·46	1·33
Pulo Peesang	......	......	......	......	......	1·51	1·00	0·20	0·00	0·92	1·32
Singapore	......	......	......	2·36	2·02	1·66	0·77	0·00	0·15	1·10	2·21
Carimon	......	......	......	......	......	1·60	0·68	0·00	0·45	1·56	2·60
Bowaya	......	......	......	......	......	1·80	0·25	0·00	0·47	1·17	2·15
Padang	......	......	......	1·91	1·83	1·62	1·05	0·27	0·00	0·17	0·45
Bencoolen	......	......	......	2·14	2·24	2·42	3·02	3·34	1·78	0·52	0·14
Batavia, Winter	2·28	2·20	2·15	2·33	2·28	2·10	1·55	0·48	0·00	0·13	0·75
Batavia, Spring	......	......	......	1·33	1·28	1·23	1·40	1·25	0·43	0·10	0·00
Cocos	......	......	......	3·28	3·44	3·41	3·81	3·36	1·75	0·39	0·00
											Declino-
Moulmein	......	......	......	1·6	1·0	0·7	1·5	2·2	2·0	2·4	1·7
Madras	......	......	......	0·81	0·81	0·94	1·80	2·90	3·29	2·54	1·64
Nicobar	......	......	......	1·44	1·24	0·88	0·08	0·00	0·38	2·19	2·96
Sambooanga	......	......	......	3·22	3·27	3·23	3·75	3·57	2·34	1·78	1·07
Penang	......	......	......	2·26	2·28	1·88	0·88	0·00	0·68	2·32	3·34
Pulo Dinding	......	......	......	4·07	3·60	3·34	2·54	0·80	0·00	1·70	4·47
Sarawak	0·84	0·92	1·37	1·22	1·26	1·39	1·88	2·57	2·09	1·00	0·37
Keemah	......	......	......	2·01	1·78	2·02	2·22	2·80	2·39	1·20	0·43
Pulo Peesang	......	......	......	......	1·00	1·75	1·06	0·00	0·18	1·02	1·26
Singapore	......	......	......	2·64	2·37	2·01	1·15	0·09	0·00	1·08	2·35
Carimon	......	......	......	......	......	1·92	0·55	0·00	0·92	2·18	3·47
Bowaya	......	......	......	......	......	2·07	0·45	0·00	0·15	1·20	2·40
Padang	......	......	......	1·91	1·82	1·58	1·03	0·18	0·00	0·35	0·98
Bencoolen	......	......	......	2·15	2·50	3·10	4·10	3·40	2·35	1·05	0·30
Batavia, Winter	3·25	3·10	2·95	2·65	2·55	2·35	1·75	0·60	0.00	0·20	0·95
Batavia, Spring	......	......	......	1·50	1·46	1·30	1·40	1·28	0·38	0·15	0·00
Cocos	......	......	......	2·70	2·82	2·73	3·13	2·63	1·08	0·00	0·15
											Declino-
Moulmein	......	......	......	2·3	1·6	1·4	2·0	2·9	3·2	3·2	2·6
Madras	......	......	......	2·01	2·11	2·15	2·99	4·43	4·60	3·47	2·10
Nicobar	......	......	......	1·26	1·12	0·70	0·00	0·02	0·80	2·18	3·54
Sambooanga.											
Penang	......	......	......	1·94	2·16	1·60	0·44	0·00	0·54	2·46	3·62
Pulo Dinding	......	......	......	3·07	2·87	2·67	1·67	0·27	0·00	1·84	4·70
Sarawak.											
Keemah	......	......	......	1·68	1·51	1·67	1·73	2·57	1·87	0·87	0·18
Pulo Peesang.											
Singapore	......	......	......	2·34	2·02	1·62	0·74	0·00	0·08	1·08	2·22
Singapore, No. IV.	......	......	......	2·50	2·76	2·29	1·44	0·13	0·00	0·90	1·99
Singapore, No. V.	......	......	......	2·04	1·83	1·54	0·59	0·00	0·02	0·98	1·99
Padang.											
Bencoolen											
Batavia, Winter.											
Batavia, Spring.											
Cocos	......	......	......	2·90	3·00	2·97	3·36	2·89	1·30	0·13	0·00

in the Eastern Archipelago.—Declinometer No. I.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
′	′	′	′	′	′	′	′	′	′	′	′	′	′
0·84	0·00	0·10	0·97	1·85	2·72	2·80	2·47	2·21	2·02	1·96	……	……	2·06
4·12	4·26	4·52	4·74	4·38	4·00	3·56	2·78	3·06	2·90	2·74	……	……	2·68
0·65	0·00	0·16	0·38	0·56	1·23	1·90	2·00	2·08	1·86	1·76	……	……	1·86
3·98	4·90	4·86	4·54	4·18	3·82	2·90	2·40	2·62	2·72	2·58	……	……	2·78
5·67	6·83	7·23	7·47	7·40	6·63	5·80	5·13	5·30	4·93	4·60	……	……	4·52
0·23	0·00	0·03	0·29	0·61	1·06	1·23	0·93	0·92	0·79	0·87	0·85	0·83	0·86
0·42	0·00	0·53	1·31	1·74	2·12	2·23	2·22	2·36	2·24	2·16	……	……	2·28
2·56	3·92	4·54	4·40	3·68	3·42	3·24	3·36	3·20	2·77	2·14	……	……	2·44
3·30	4·21	5·11	4·96	4·75	4·18	3·55	3·30	3·31	3·04	2·97	……	……	2·77
3·15	3·35	3·21	2·80	1·95	1·36	1·10	1·33	1·58	1·80	……	……	……	1·78
3·17	3·72	3·52	2·97	2·45	2·40	2·32	2·47	2·32	2·20	……	……	……	2·09
1·26	2·43	3·05	3·24	3·24	3·13	2·66	2·35	2·46	2·18	1·85	……	……	1·85
0·00	0·38	1·18	2·06	3·20	3·48	2·40	1·80	1·54	1·32	0·98	……	……	1·79
1·75	3·13	4·33	4·68	4·53	4·05	3·48	3·10	3·08	2·88	2·61	2·15	2·11	2·43
0·23	0·65	1·13	1·63	2·06	2·10	1·80	1·45	1·20	0·93	0·58	……	……	1·10
0·38	1·44	2·69	3·72	4·26	4·32	3·78	3·22	3·30	2·99	2·97	……	……	2·76

meter No. II.

0·8	0·00	0·00	0·4	1·1	1·9	2·3	2·3	1·9	1·4	1·3	……	……	1·4
0·69	0·00	0·25	0·89	1·68	2·13	1·91	1·34	1·00	0·67	0·53	……	……	1·34
3·72	3·78	3·98	4·10	3·70	3·24	2·80	1·92	2·30	2·24	2·12	……	……	2·27
1·08	0·00	0·15	0·65	0·77	1·60	2·17	2·17	2·15	1·95	1·98	……	……	1·94
3·10	4·24	4·16	3·82	3·44	3·02	2·20	1·24	1·88	1·84	1·66	……	……	2·42
5·84	6·44	6·84	7·40	7·44	6·80	5·94	5·07	5·20	4·64	4·37	……	……	4·55
0·13	0·00	0·19	0·67	1·24	1·76	1·96	1·52	1·21	0·97	1·05	0·98	0·83	1·14
0·11	0·00	0·70	1·19	1·46	1·69	1·75	1·59	1·54	1·44	1·13	……	……	1·45
1·76	2·46	3·26	3·08	2·38	2·22	2·15	1·96	1·96	1·78	1·73	……	……	1·72
3·58	4·50	5·53	5·43	5·18	4·63	4·00	3·71	3·64	3·41	3·06	……	……	3·07
4·23	4·67	4·60	4·37	3·68	3·25	2·83	2·95	2·88	2·60	……	……	……	2·83
3·35	3·78	3·63	3·33	2·85	2·83	2·78	2·80	2·75	2·23	……	……	……	2·29
2·09	3·56	4·49	4·82	4·80	4·38	3·72	3·23	3·15	2·63	2·28	……	……	2·47
0·00	0·35	1·45	3·10	4·30	4·25	4·00	4·15	3·95	3·70	3·05	……	……	2·69
2·10	3·90	5·12	5·70	5·67	5·25	4·63	4·17	4·05	3·90	3·60	3·22	3·07	3·10
0·50	1·13	1·83	2·48	3·03	3·18	2·96	2·50	2·26	1·88	1·40	……	……	1·58
0·89	2·17	3·33	4·33	4·72	4·55	3·91	3·10	2·71	2·60	2·29	……	……	2·62

meter No. III.

1·4	0·2	0·00	0·5	1·5	2·7	3·3	2·9	2·2	1·6	1·4	……	……	1·9
0·87	0·00	0·05	0·70	1·68	2·39	2·43	1·86	1·62	1·45	1·43	……	……	2·02
4·00	4·10	4·22	4·22	3·96	3·50	3·06	2·37	2·67	2·59	2·49	……	……	2·46
4·16	5·28	5·62	5·04	4·82	4·52	3·86	3·44	3·62	3·72	3·40	……	……	3·17
6·17	7·14	7·74	7·97	7·74	6·70	5·60	4·54	4·57	4·14	3·80	……	……	4·38
0·00	0·06	0·82	1·58	2·01	2·30	2·31	2·17	2·04	1·76	1·45	……	……	1·52
3·36	4·26	5·15	5·00	4·77	4·23	3·59	3·29	3·30	2·97	2·60	……	……	2·77
3·02	3·99	4·97	4·89	4·72	4·25	3·77	3·57	3·38	3·09	3·16	……	……	2·89
2·94	3·90	4·88	4·75	4·48	4·08	3·40	3·17	3·12	2·89	2·62	……	……	2·59
0·73	2·06	3·46	4·47	5·01	5·01	4·40	3·61	3·57	3·15	2·84	……	……	2·89

Oscillation of Declination at Singa-

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
	′	′	′	′	′	′	′	′	′	′	′
November ......1848...	......	......	......	2·27	3·02	2·40	1·52	0·16	0·00	0·85	1·96
December	......	......	......	2·74	2·50	2·19	1·36	0·10	0·00	0·96	2·02
Sums	......	......	......	5·01	5·52	4·59	2·88	0·26	0·00	1·81	3·98
Means	......	......	......	2·50	2·76	2·29	1·44	0·13	0·00	0·90	1·99
Oscillation	......	......	......	2·50	2·76	2·29	1·44	0·13	0·00	0·90	1·99

No.

November ......1848...	... ..	......	......	2·20	1·99	1·66	0·76	0·38	0·00	1·14	2·24
December	......	......	......	2·26	2·05	1·80	0·80	0·00	0·43	1·21	2·12
Sums	......	......	......	4·46	4·04	3·46	1·56	0·38	0·43	2·35	4·36
Means	......	......	......	2·23	2·02	1·73	0·78	0·19	0·21	1·17	2·18
Oscillation	......	......	......	2·04	1·83	1·54	0·59	0·00	0·02	0·98	1·99

Oscillation of the Declination at Batavia in Java,

November ......1846...	2·3	1·9	2·0	1·8	1·7	1·7	0·8	0·2	0·0	0·4	1·1
December ....,.	2·6	2·5	2·5	2·3	2·2	1·8	1·1	0·1	0·0	0·4	1·4
January ....1847...	2·2	2·3	2·1	2·6	2·5	2·2	1·7	0·3	0·0	0·4	0·9
February	2·7	2·8	2·7	3·3	3·4	3·4	3·3	2·0	0·7	0·0	0·3
Sums	9·8	9·5	9·3	10·0	9·8	9·1	6·9	2·6	0·7	1·2	3·7
Means	2·45	2·37	2·32	2·50	2·45	2·27	1·72	0·65	0·17	0·30	0·92
Oscillation	2·28	2·20	2·15	2·33	2·28	2·10	1·55	0·48	0·00	0·13	0·75

Oscillation of the Declination at Batavia in Java,

March ....1847...	......	......	......	1·8	1·6	1·4	1·3	0·7	0·0	1·1	0·7
April	......	......	......	2·7	2·6	2·4	2·5	1·9	0·9	0·0	0·4
May	......	......	......	1·6	1·6	1·7	2·1	2·1	1·2	0·4	0·0
June	......	......	......	0·9	1·0	1·1	1·4	2·0	1·3	0·6	0·6
Sums	......	......	......	7·0	6·8	6·6	7·3	6·7	3·4	2·1	1·7
Means	......	......	......	1·75	1·70	1·65	1·82	1·67	0·85	0·52	0·42
Oscillation	......	......	......	1·33	1·28	1·23	1·40	1·25	0·43	0·10	0·00

Oscillation of the Declination at Sarawak in Borneo,

June ....1846...	1·17	1·38	1·61	1·79	1·83	2·02	2·52	3·24	2·70	1·73	0·96
July	0·80	0·93	1·24	1·42	1·63	1·77	2·27	2·92	2·36	1·43	0·75
August	1·18	1·22	1·33	1·55	1·70	1·88	2·58	3·64	3·09	1·67	1·19
Sums	3·15	3·53	4·18	4·76	5·16	5·67	7·37	9·80	8·15	4·83	2·90
Means	1·05	1·18	1·39	1·59	1·72	1·89	2·46	3·27	2·72	1·61	0·97
Oscillation	1·00	1·13	1·34	1·54	1·67	1·84	2·41	3·22	2·67	1·56	0·92

Oscillation of the Declination at Padang in Sumatra,

October ....1847...	......	......	......	1·61	1·53	1·55	1·43	1·12	0·68	0·48	0·00
November	......	......	......	1·82	1·84	1·54	0·83	0·00	0·13	0·18	0·69
December	......	......	......	2·78	2·69	2·36	1·67	0·61	0·00	0·46	1·16
January ....1848...	......	......	......	2·22	2·07	1·85	1·08	0·17	0·00	0·37	0·76
Sums	......	......	......	8·43	8·13	7·30	5·01	1·90	0·81	1·49	2·51
Means	......	......	......	2·11	2·03	1·82	1·25	0·47	0·20	0·37	0·65
Oscillation	......	......	......	1·91	1·83	1·62	1·05	0·27	0·00	0·17	0·45

pore, Eastern Archipelago.—No. IV.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
3·12′	3·95′	5·04′	4·87′	5·07′	4·41′	3·96′	3·96′	3·40′	3·00′	2·58′	′	′	2·98′
2·93	4·04	4·90	4·92	4·37	4·09	3·59	3·19	3·36	3·19	3·74	......	......	2·80
6·05	7·99	9·94	9·79	9·44	8·50	7·55	7·15	6·76	6·19	6·32	......	......	5·78
3·02	3·99	4·97	4·89	4·72	4·25	3·77	3·57	3·38	3·09	3·16	......	......	2·89
3·02	3·99	4·97	4·89	4·72	4·25	3·77	3·57	3·38	3·09	3·16	......	......	2·89

V.

3·29	4·27	5·31	4·99	4·96	4·59	3·88	3·89	3·72	3·41	3·14	......	......	2·94
2·97	3·92	4·83	4·89	4·39	3·95	3·31	2·83	2·90	2·75	2·49	......	......	2·63
6·26	8·19	10·14	9·88	9·35	8·54	7·19	6·72	6·62	6·16	5·63	......	......	5·57
3·13	4·09	5·07	4·94	4·67	4·27	3·59	3·36	3·31	3·08	2·81	......	......	2·78
2·94	3·90	4·88	4·75	4·48	4·08	3·40	3·17	3·12	2·89	2·62	......	......	2·59

Eastern Archipelago.—Declinometer No. I.

2·2	3·3	4·6	4·6	4·3	3·9	3·6	3·0	2·9	2·6	2·5	2·2	2·2	2·3
2·2	3·4	4·2	4·4	4·2	3·9	3·3	2·9	2·9	2·8	2·7	2·5	2·3	2·5
1·8	3·2	4·3	4·5	4·3	3·6	3·1	3·0	3·1	2·9	2·2	2·0	2·0	2·4
1·5	3·3	4·9	5·9	6·0	5·5	4·6	4·2	4·1	3·9	3·7	2·5	2·6	3·3
7·7	13·2	18·0	19·4	18·8	16·9	14·6	13·1	13·0	12·2	11·1	9·2	9·1	10·5
1·92	3·30	4·50	4·85	4·70	4·22	3·65	3·27	3·25	3·05	2·78	2·30	2·28	2·62
1·75	3·13	4·33	4·68	4·53	4·05	3·48	3·10	3·08	2·88	2·61	2·15	2·11	2·43

Eastern Archipelago.—Declinometer No. I.

1·4	2·1	2·5	2·8	2·7	2·6	2·3	2·2	2·1	1·9	1·3	......	......	1·7
1·2	2·0	2·6	3·0	3·3	3·1	3·0	2·9	2·6	2·3	2·1	......	......	2·2
0·0	0·1	0·7	1·5	2·2	2·6	2·3	1·7	1·3	0·9	0·6	......	......	1·3
0·0	0·1	0·4	0·9	1·7	1·8	1·3	0·7	0·5	0·3	0·0	......	......	0·9
2·6	4·3	6·2	8·2	9·9	10·1	8·9	7·5	6·5	5·4	4·0	......	......	6·1
0·65	1·07	1·55	2·05	2·48	2·52	2·22	1·87	1·62	1·35	1·00	......	......	1·52
0·23	0·63	1·13	1·63	2·06	2·10	1·80	1·45	1·20	0·93	0·58	......	......	1·10

Eastern Archipelago.—Declinometer No. I.

0·42	0·08	0·00	0·27	0·53	0·87	0·91	0·71	0·85	0·72	0·81	0·87	0·92	1·20
0·29	0·08	0·00	0·11	0·43	0·79	1·08	0·78	0·64	0·54	0·52	0·55	0·59	1·00
0·13	0·00	0·23	0·65	1·02	1·67	1·86	1·46	1·42	1·27	1·42	1·28	1·14	1·42
0·84	0·16	0·23	1·03	1·98	3·33	3·85	2·95	2·91	2·53	2·75	2·70	2·65	3·62
0·28	0·05	0·08	0·34	0·66	1·11	1·28	0·98	0 97	0·84	0·92	0·90	0·88	0·91
0·23	0·00	0·03	0·29	0·61	1·06	1·23	0·93	0·92	0·79	0·87	0·85	0·83	0·86

Eastern Archipelago.—Declinometer No. I.

0·78	2·12	2·91	3·13	2 90	2·83	2·43	2·28	2·03	1·78	1·33	......	......	1·73
1·83	2·79	3·34	3·45	3·18	2·93	2·55	2·36	2·36	2·08	1·81	......	......	1·88
1·97	3·18	3·75	3·95	4·25	4·16	3·69	3·04	3·15	3·10	2·85	......	......	2·57
1·25	2·42	3·00	3·24	3·45	3·39	2·79	2·52	3·12	2·55	2·22	......	......	8·02
5·83	10·51	13·00	13·77	13·78	13·31	11·46	10·20	10·66	9·51	8·21	......	......	8·20
1·46	2·63	3·25	3·44	3·44	3·33	2·86	2·55	2·66	2·38	2·05	......	......	2·05
1·26	2·43	3·05	3·24	3·24	3·13	2·66	2·35	2·46	2·18	1·85	......	......	1·85

Oscillation of the Declination at Singapore,

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
	′	′	′	′	′	′	′	′	′	′	′
November ......1848...	......	......	......	2·33	1·94	1·53	0·70	0·00	0·10	0·93	2·16
December	......	......	......	2·38	2·11	1·79	0·85	0·00	0·21	1·28	2·27
Means	......	......	......	2·36	2·02	1·66	0·77	0·00	0·15	1·10	2·21

Oscillation of the Declination at Batavia in

November ...1846......	2·4	2·2	2·1	1·9	1·8	1·7	0·9	0·1	0·0	0·4	1·2
December	3·2	3·0	2·9	2·7	2·4	2·1	1·3	0·3	0·0	0·5	1·5
January ......1847......	3·7	3·7	3·6	2·9	2·7	2·4	1·8	0·4	0·0	0·5	1·2
February	3·9	4·1	3·8	3·7	3·8	3·7	3·5	2·2	0·6	0·0	0·5
Sums	13·2	13·0	12·4	11·2	10·7	9·9	7·5	3·0	0·6	1·4	4·4
Means	3·40	3·25	3·10	2·80	2·70	2·50	1·90	0·75	0·15	0·35	1·10
Oscillation	3·25	3·10	2·95	2·65	2·55	2·35	1·75	0·60	0·00	0·20	0·95

Oscillation of the Declination at Batavia in

March ......1847......	......	......	......	2·3	2·1	1·7	1·5	0·9	0·0	1·2	0·8
April	......	......	......	2·8	2·7	2·5	2·4	2·0	0·8	0·0	0·5
May	......	......	......	1·6	1·6	1·6	2·0	1·9	1·1	0·4	0·0
June	......	......	......	0·6	0·7	0·7	1·0	1·6	0·9	0·3	0·0
Sums	......	......	......	7·3	7·1	6·5	6·9	6·4	2·8	1·9	1·3
Means	......	......	......	1·82	1·78	1·62	1·72	1·60	0·70	0·47	0·32
Oscillation	......	......	......	1·50	1·46	1·30	1·40	1·28	0·38	0·15	0·00

Oscillation of the Declinometer No. III.

November ...1848......	......	......	......	2·32	1·92	1·48	0·64	0·09	0·00	0·94	2·16
December	......	......	......	2·45	2·20	1·84	0·93	0·00	0·25	1·30	2·36
Means	......	......	......	2·38	2·06	1·66	0·78	0·04	0·12	1·12	2·26
Oscillation	......	......	......	2·34	2·02	1·62	0·74	0·00	0·08	1·08	2·22

Oscillation of the Declination at Sarawak in

June ....1846......	0·65	0·84	1·03	1·14	1·14	1·28	1·76	2·45	1·86	1·00	0·41
July	1·19	1·23	2·23	1·58	1·64	1·61	1·89	2·42	2·00	0·86	0·19
August	0·68	0·69	0·85	0·94	1·01	1·29	1·98	2·85	2·40	1·15	0·51
Sums	2·52	2·76	4·11	3·66	3·79	4·18	5·63	7·72	6·26	3·01	1·11
Means	0·84	0·92	1·37	1·22	1·26	1·39	1·88	2·57	2·09	1·00	0·37
Oscillation	0·84	0·92	1·37	1·22	1·26	1·39	1·88	2·57	2·09	1·00	0·37

Oscillation of the Declination at Padang in Sumatra,

October ......1847......	......	......	......	1·21	1·15	1·12	0·98	0·61	0·22	0·03	0·00
November	......	......	......	1·98	1·94	1·64	0·94	0·00	0·16	0·29	1·06
December	......	......	......	2·66	2·59	2·26	1·65	0·43	0·00	0·71	1·81
January ......1848......	......	......	......	2·15	1·97	1·67	0·92	0·05	0·00	0·75	1·41
Sums	......	......	......	8·00	7·65	6·69	4·49	1·09	0·38	1·78	4·28
Means	......	......	......	2·00	1·91	1·67	1·12	0·27	0·09	0·44	1·07
Oscillation	......	......	......	1·91	1·82	1·58	1·03	0·18	0·00	0·35	0·98

Eastern Archipelago.—Declinometer No. I.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
′	′	′	′	′	′	′	′	′	′	′	′	′	′
3·47	4·24	5·22	5·02	5·07	4·35	3·76	3·74	3·60	3·33	2·94	……	……	2·86
3·12	4·19	5·01	4·90	4·42	4·02	3·33	2·85	3·03	2·75	3·01	……	……	2·68
3·30	4·21	5·11	4·96	4·75	4·18	3·55	3·30	3·31	3·04	2·97	……	……	2·77

Java, Eastern Archipelago.—Declinometer No. II.

2·4	3·9	4·8	5·2	5·0	4·6	4·0	3·4	3·2	2·8	2·6	2·3	2·3	2·5
2·5	4·2	5·3	5·7	5·6	5·4	4·9	4·3	4·2	3·9	3·5	3·2	2·8	3·3
2·0	4·0	5·1	5·5	5·5	4·9	4·4	4·2	4·2	4·5	4·2	3·8	3·6	3·2
2·1	4·1	5·9	7·0	7·2	6·7	5·8	5·4	5·2	5·0	4·7	4·2	4·2	4·0
9·0	16·2	21·1	23·4	23·3	21·6	19·1	17·3	16·8	16·2	15·0	13·5	12·9	13·0
2·25	4·05	5·27	5·85	5·82	5·40	4·78	4·32	4·20	4·05	3·75	3·37	3·22	3·25
2·10	3·90	5·12	5·70	5·67	5·25	4·63	4·17	4·05	3·90	3·60	3·22	3·07	3·10

Java, Eastern Archipelago.—Declinometer No. II.

1·8	2·7	3·3	3·7	3·7	3·7	3·6	3·4	3·3	3·0	2·2	……	……	2·3
1·3	2·3	3·1	3·7	4·1	4·0	3·9	3·8	3·4	3·1	2·7	……	……	2·5
0·1	0·5	1·3	2·1	3·0	3·4	3·1	2·4	2·0	1·5	1·1	……	……	1·6
0·1	0·3	0·9	1·7	2·6	2·9	2·5	1·7	1·6	1·2	0·9	……	……	1·2
3·3	5·8	8·6	11·2	13·4	14·0	13·1	11·3	10·3	8·8	6·9	……	……	7·6
0·82	1·45	2·15	2·80	3·35	3·50	3·28	2·82	2·58	2·20	1·72	……	……	1·90
0·50	1·13	1·83	2·48	3·03	3·18	2·96	2·50	2·26	1·88	1·40	……	……	1·58

at Singapore, Eastern Archipelago.

3·57	4·29	5·29	5·04	5·09	4·40	3·80	3·69	3·54	3·19	2·85	……	……	2·86
3·23	4·31	5·10	5·04	4·53	4·14	3·47	2·97	3·15	2·83	2·44	……	……	2·77
3·40	4·30	5·19	5·04	4·81	4·27	3·63	3·33	3·34	3·01	2·64	……	……	2·81
3·36	4·26	5·15	5·00	4·77	4·23	3·59	3·29	3·30	2·97	2·60	……	……	2·77

Borneo, Eastern Archipelago.—Declinometer No. II.

0·17	0·00	0·16	0·63	0·93	1·24	1·35	0·99	0·88	0·55	0·63	0·57	0·57	0·93
0·15	0·01	0·00	0·36	1·28	1·67	2·11	1·69	1·39	1·31	1·35	1·23	1·18	1·26
0·08	0·00	0·42	1·03	1·50	2·36	2·41	1·87	1·35	1·06	1·16	0·93	0·75	1·22
0·40	0·01	0·58	2·02	3·71	5·27	5·87	4·55	3·62	2·92	3·14	2·73	2·50	3·41
0·13	0·00	0·19	0·67	1·24	1·76	1·96	1·52	1·21	0·97	1·05	0·98	0·83	1·14
0·13	0·00	0·19	0·67	1·24	1·76	1·96	1·52	1·21	0·97	1·05	0·98	0·83	1·14

Eastern Archipelago.—Declinometer No. II.

0·98	2·59	3·80	4·16	3·80	3·12	2·53	2·43	2·20	1·61	1·23	……	……	1·78
2·45	3·69	4·40	4·61	4·39	4·04	3·51	3·14	2·98	2·56	2·27	……	……	2·42
3·01	4·53	5·41	5·71	6·10	5·76	5·08	4·07	3·88	3·56	3·21	……	……	3·29
2·28	3·78	4·69	5·14	5·29	4·96	4·12	3·63	3·87	3·16	2·77	……	……	2·77
8·72	14·59	18·30	19·62	19·58	17·88	15·24	13·27	12·93	10·89	9·48	……	……	10·26
2·18	3·65	4·58	4·91	4·89	4·47	3·81	3·32	3·24	2·72	2·37	……	……	2·56
2·09	3·56	4·49	4·82	4·80	4·38	3·72	3·23	3·15	2·63	2·28	……	……	2·47

Oscillation of the Declination at Singapore,

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
	′	′	′	′	′	′	′	′	′	′	′
November 1848	......	......	......	2·61	2·29	1·82	1·05	0·22	0·00	0·92	2·25
December	......	......	......	2·72	2·50	2·25	1·29	0·00	0·04	1·28	2·50
Mean	......	......	......	2·66	2·39	2·03	1·17	0·11	0·02	1·10	2·37
Oscillation	......	......	......	2·64	2·37	2·01	1·15	0·09	0·00	1·08	2·35

Mean Hourly Oscillation of the Magnetic Declination at Singapore

December	2·34	2·34	2·27	2·16	2·08	1·72	0·88	0·00	0·01	0·64	1·49
January	2·43	2·35	2·24	2·10	1·88	1·53	0·91	0·03	0·00	0·62	1·15
February	2·88	2·82	2·80	2·82	2·67	2·47	1·93	0·78	0·04	0·00	0·52
Sums	7·65	7·51	7·31	7·08	6·63	5·72	3·72	0·81	0·05	1·26	3·16
Means	2·55	2·50	2·44	2·36	2·21	1·91	1·24	0·27	0·02	0·42	1·05
Oscillation	2·53	2·48	2·42	2·34	2·19	1·89	1·22	0·25	0·00	0·40	1·03

Mean Hourly Oscillation of the Magnetic Declina-

March	1·25	1·30	1·28	1·24	1·18	1·15	1·16	0·71	0·00	0·11	0·75
April	1·22	1·38	1·44	1·43	1·31	1·22	1·66	1·43	0·47	0·00	0·28
May	1·56	1·73	1·91	1·96	2·01	2·11	3·05	3·34	2·07	1·00	0·42
Sums	4·03	4·41	4·63	4·63	4·50	4·58	5·87	5·48	2·54	1·11	1·45
Means	1·34	1·47	1·54	1·54	1·50	1·53	1·96	1·83	0·85	0·37	0·48
Oscillation	0·97	1·10	1·17	1·17	1·13	1·16	1·59	1·46	0·48	0·00	0·11

Mean Hourly Oscillation of the Magnetic Declina-

June	0·55	0·78	0·86	1·00	1·03	1·21	1·96	2·32	1·23	0·62	0·00
July	0·77	1·01	1·20	1·13	1·15	1·65	2·44	2·87	1·89	0·78	0·15
August	1·81	2·01	2·09	2·18	2·24	2·52	3·66	4·05	2·59	1·13	0·23
Sums	3·13	3·80	4·15	4·31	4·42	5·38	8·06	9·24	5·71	2·53	0·38
Means	1·04	1·27	1·38	1·44	1·47	1·79	2·69	3·08	1·90	0·84	0·13
Oscillation	0·97	1·20	1·31	1·37	1·40	1·72	2·62	3·01	1·83	0·77	0·06

Mean Hourly Oscillation of the Magnetic Declina-

September	1·67	1·83	1·85	1·91	2·01	2·07	2·86	2·57	1·12	0·26	0·00
October	2·06	2·02	2·02	1·90	1·82	1·64	1·68	0·84	0·18	0·00	0·42
November	2·06	2·09	2·04	1·90	1·68	1·45	0·68	0·00	0·02	0·35	1·16
Sums	5·79	5·94	5·91	5·71	5·51	5·16	5·22	3·41	1·32	0·61	1·58
Means	1·93	1·98	1·97	1·90	1·84	1·72	1·74	1·14	0·44	0·20	0·53
Oscillation	1·73	1·78	1·77	1·70	1·64	1·52	1·54	0·94	0·24	0·00	0·33

Mean Hourly Oscillation of the Magnetic Decli-

Winter	2·53	2·48	2·42	2·34	2·19	1·89	1·22	0·25	0·00	0·40	1·03
Spring	0·97	1·10	1·17	1·17	1·13	1·16	1·59	1·46	0·48	0·00	0·11
Summer	0·97	1·20	1·31	1·37	1·40	1·72	2·62	3·01	1·83	0·77	0·06
Autumn	1·73	1·78	1·77	1·70	1·64	1·52	1·54	0·94	0·24	0·00	0·33
Sums	6·20	6·56	6·67	6·58	6·36	6·29	6·97	5·66	2·55	1·17	1·53
Means	1·55	1·64	1·67	1·64	1·59	1·57	1·74	1·41	0·64	0·29	0·38
Oscillation	1·26	1·35	1·38	1·35	1·30	1·28	1·45	1·12	0·35	0·00	0·09

Eastern Archipelago.—Declinometer No. II.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
3′·64	4′·52	5′·68	5′·40	5′·50	4′·80	4′·19	4′·15	3′·94	3′·68	3′·32	......	......	3′·16
3·55	4·53	5·42	5·50	4·90	4·51	3·86	3·31	3·38	3·18	2·85	......	......	3·03
3·60	4·52	5·55	5·45	5·20	4·65	4·02	3·73	3·66	3·43	3·08	......	......	3·09
3·58	4·50	5·53	5·43	5·18	4·63	4·00	3·71	3·64	3·41	3·06	......	......	3·07
in the Winter Months of 1843, 1844, 1845.—Scale Divisions.													
2·60	3·70	4·40	4·43	4·35	4·20	3·60	3·19	3·01	2·86	2·65	2·49	2·41	2·49
1·80	2·97	3·74	4·09	4·00	3·70	3·29	3·14	3·17	2·97	2·85	2·66	2·46	2·34
2·12	3·36	4·32	4·63	4·49	4·08	3·72	3·43	3·39	3·21	3·02	2·84	2·81	2·70
6·52	10·03	12·46	13·15	12·84	11·98	10·61	9·76	9·57	9·04	8·52	7·99	7·68	7·53
2·17	3·34	4·15	4·38	4·28	3·99	3·54	3·25	3·19	3·01	2·84	2·66	2·56	2·51
2·15	3·32	4·13	4·36	4·26	3·97	3·52	3·23	3·17	2·99	2·82	2·64	2·54	2·49
tion in the Spring Months of 1843, 1844, 1845.													
1·52	1·90	2·09	2·41	2·59	2·35	2·08	1·88	1·61	1·38	1·27	1·21	1·19	1·40
0·58	0·53	0·90	1·09	1·50	1·72	1·67	1·44	1·17	0·93	0·82	0·92	1·04	1·09
0·00	0·09	0·71	1·21	1·66	2·04	1·44	1·48	1·27	1·08	1·00	1·11	1·16	1·49
2·10	2·52	3·70	4·71	5·75	6·11	5·19	4·80	4·05	3·39	3·09	3·24	3·39	3·98
0·70	0·84	1·23	1·57	1·92	2·04	1·73	1·60	1·35	1·13	1·03	1·08	1·13	1·33
0·33	0·47	0·86	1·20	1·55	1·67	1·36	1·23	0·98	0·76	0·66	0·71	0·76	0·96
tion in the Summer Months of 1843, 1844, 1845.													
0·22	0·29	0·62	0·79	0·89	0·77	0·54	0·15	0·04	0·03	0·04	0·08	0·25	0·58
0·00	0·07	0·55	0·89	1·26	1·49	1·31	0·74	0·48	0·35	0·31	0·39	0·52	0·99
0·00	0·32	0·95	1·46	2·25	2·39	2·66	2·14	1·91	1·63	1·52	1·51	1·66	1·89
0·22	0·68	2·12	3·14	4·40	4·65	4·51	3·03	2·43	2·01	1·87	1·98	2·43	3·46
0·07	0·23	0·71	1·05	1·47	1·55	1·50	1·01	0·81	0·67	0·62	0·66	0·81	1·15
0·00	0·16	0·64	0·98	1·40	1·48	1·43	0·94	0·74	0·60	0·57	0·59	0·74	1·08
tion in the Autumn Months of 1843, 1844, 1845.													
0·26	0·71	1·34	1·97	2·43	2·37	2·26	2·15	1·91	1·68	1·60	1·53	1·55	1·97
1·50	2·77	3·38	3·42	3·20	2·86	2·61	2·59	2·40	2·18	2·03	1·92	1·88	1·97
2·37	3·61	4·25	4·41	4·17	3·61	3·05	2·88	2·72	2·46	2·27	2·01	2·03	2·22
4·13	7·09	8·97	9·80	9·80	8·84	7·92	7·62	7·03	6·32	5·90	5·46	5·46	6·16
1·38	2·36	2·99	3·27	3·27	2·95	2·64	2·54	2·34	2·11	1·97	1·82	1·82	2·05
1·18	2·16	2·79	3·07	3·07	2·75	2·44	2·34	2·14	1·91	1·77	1·62	1·62	1·85
nation in the four Seasons of 1843, 1844, 1845.													
2·15	3·32	4·13	4·36	4·26	3·97	3·52	3·23	3·17	2·99	2·82	2·64	2·54	2·49
0·33	0·47	0·86	1·20	1·55	1·67	1·36	1·23	0·98	0·76	0·66	0·71	0·76	0·96
0·00	0·16	0·64	0·98	1·40	1·48	1·43	0·94	0·74	0·60	0·57	0·59	0·74	1·08
1·18	2·16	2·79	3·07	3·07	2·75	2·44	2·34	2·14	1·91	1·77	1·62	1·62	1·85
3·66	6·11	8·42	9·61	10·28	9·87	8·75	7·74	7·03	6·26	5·82	5·56	5·66	6·38
0·91	1·53	2·11	2·40	2·57	2·47	2·19	1·93	1·76	1·56	1·45	1·39	1·41	1·59
0·62	1·24	1·82	2·11	2·28	2·18	1·90	1·64	1·47	1·27	1·16	1·10	1·12	1·30

Mean Hourly Oscillation of the Magnetic Declina-

Singapore Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
December	2·34	2·34	2·27	2·16	2·08	1·72	0·88	0·00	0·01	0·64	1·49
January	2·43	2·35	2·24	2·10	1·88	1·53	0·91	0·03	0·00	0·62	1·15
February	2·88	2·82	2·80	2·82	2·67	2·47	1·93	0·78	0·04	0·00	0·52
March	1·25	1·30	1·28	1·24	1·18	1·15	1·16	0·71	0·00	0·11	0·75
April	1·22	1·38	1·44	1·43	1·31	1·22	1·66	1·43	0·47	0·00	0·28
May	1·56	1·73	1·91	1·96	2·01	2·11	3·05	3·34	2·07	1·00	0·42
June	0·55	0·78	0·86	1·00	1·03	1·21	1·96	2·32	1·23	0·62	0·00
July	0·77	1·01	1·20	1·13	1·15	1·65	2·44	2·87	1·89	0·78	0·15
August	1·81	2·01	2·09	2·18	2·24	2·52	3·66	4·05	2·59	1·13	0·23
September	1·67	1·83	1·85	1·91	2·01	2·07	2·86	2·57	1·12	0·26	0·00
October	2·06	2·02	2·02	1·90	1·82	1·64	1·68	0·84	0·18	0·00	0·42
November	2·06	2·09	2·04	1·90	1·68	1·45	0·68	0·00	0·02	0·35	1·16
Sums	20·60	21·66	22·00	21·73	21·06	20·74	22·87	18·94	9·62	5·51	6·57
Means	1·72	1·81	1·88	1·81	1·76	1·78	1·91	1·58	0·80	0·46	0·55
Oscillation	1·26	1·35	1·37	1·35	1·30	1·27	1·45	1·12	0·35	0·00	0·09

Mean Oscillation of the Magnetic Declination at Singapore

1843	1·31	1·37	1·41	1·32	1·30	1·20	1·36	1·02	0·37	0·00	0·10
1844	1·36	1·46	1·49	1·51	1·46	1·41	1·57	1·23	0·38	0·00	0·04
1845	1·13	1·21	1·24	1·24	1·21	1·20	1·41	1·13	0·37	0·00	0·14
Sums	3·80	4·04	4·14	4·07	3·97	3·81	4·34	3·38	1·12	0·00	0·28
Oscillation	1·27	1·35	1·38	1·36	1·32	1·27	1·45	1·13	0·37	0·00	0·09

tion for each Month of the Years 1843, 1844, 1845.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
2′·60	3′·70	4′·40	4′·43	4′·35	4′·20	3′·60	3′·19	3′·01	2′·86	2′·65	2′·49	2′·41	2′·49
1·80	2·97	3·74	4·09	4·00	3·70	3·29	3·14	3·17	2·97	2·85	2·66	2·46	2·34
2·12	3·36	4·32	4·63	4·49	4·08	3·72	3·43	3·39	3·21	3·02	2·84	2·81	2·70
1·52	1·90	2·09	2·41	2·59	2·35	2·08	1·88	1·61	1·38	1·27	1·21	1·19	1·40
0·58	0·53	0·90	1·09	1·50	1·72	1·67	1·44	1·17	0·93	0·82	0·92	1·04	1·09
0·00	0·09	0·71	1·21	1·66	2·04	1·44	1·48	1·27	1·08	1·00	1·11	1·16	1·49
0·22	0·29	0·62	0·79	0·89	0·77	0·54	0·15	0·04	0·03	0·04	0·08	0·25	0·58
0·00	0·07	0·55	0·89	1·26	1·49	1·31	0·74	0·48	0·35	0·31	0·39	0·52	0·99
0·00	0·32	0·95	1·46	2·25	2·39	2·66	2·14	1·91	1·63	1·52	1·51	1·66	1·89
0·26	0·71	1·34	1·97	2·43	2·37	2·26	2·15	1·91	1·68	1·60	1·53	1·55	1·97
1·50	2·77	3·38	3·42	3·20	2·86	2·61	2·59	2·40	2·18	2·03	1·92	1·88	1·97
2·37	3·61	4·25	4·41	4·17	3·61	3·05	2·88	2·72	2·46	2·27	2·01	2·03	2·22
12·97	20·32	27·25	30·80	32·79	31·58	28·23	25·21	23·08	20·76	19·38	18·67	18·96	21·13
1·08	1·69	2·27	2·57	2·73	2·63	2·35	2·10	1·92	1·73	1·61	1·55	1·58	1·76
0·61	1·22	1·80	2·10	2·27	2·17	1·90	1·64	1·46	1·27	1·15	1·09	1·12	1·30

during the three years of 1843, 1844, 1845, in Scale Divisions.

0·58	1·20	1·84	2·09	2·24	2·20	1·89	1·52	1·42	1·24	1·18	1·08	1·16	1·27
0·51	1·19	1·84	2·18	2·38	2·28	1·96	1·70	1·50	1·35	1·19	1·13	1·20	1·35
0·57	1·16	1·62	1·92	2·14	2·14	1·94	1·68	1·48	1·24	1·08	0·99	1·02	1·22
1·66	3·55	5·30	6·19	6·76	6·62	5·79	4·90	4·40	3·83	3·45	3·20	3·38	
0·56	1·19	1·78	2·07	2·25	2·20	1·92	1·63	1·47	1·28	1·15	1·06	1·12	1·28

TABLE A.

Observatory at Moulmein.—Hourly observations made during th

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$\alpha\left(1+\frac{H}{F}\right)=1'\times1{\cdot}000343=1'{\cdot}000343$. Declinometer No. I										
Sums	366·6	362·6	360·7	365·8	370·7	369·7	372·2	367·8	361·4	355·
Means of 7 days......	52·37	51·80	51·53	52·26	52·96	52·81	53·17	52·54	51·63	50·7
Diurnal changes......	+0·2	−0·4	−0·7	+0·1	+0′·8	+0·6	+1′·0	+0′·3	−0′·6	−1′·
Diurnal oscillation ...	1·6	1·0	0·7	1·5	2·2	2·0	2·4	1·7	0·8	0·
Diurnal declination	19′ 21″ +2°	18·45	18′ 27″	19′ 15″	19′ 57″	19′ 45″	20′ 09″	19′ 27″	18′ 33″	17′ 45
$\alpha\left(1+\frac{H}{F}\right)=1{\cdot}004\times1{\cdot}0004=1'{\cdot}0044$. Declinometer No. I.										
Sums	593·3	590·1	588·9	592·2	596·4	597·9	597·9	594·9	588·9	582·
Means of 5 days......	118·66	118·02	117·78	118·44	119·28	119·58	119·58	118·98	117·78	116·5
Diurnal changes......	+0′·4	−0′·3	−0′·5	+0′·1	+1′·0	+1′·3	+1′·3	+0′·7	−0′·5	−1′·
Diurnal oscillation...	2·3	1′·6	1′·4	2′·0	2′·9	3·2	3′·2	2′·6	1′·4	0′·
Diurnal declination .	19′ 15″ +2°	18′ 33″	18′ 21″	18′ 57″	19′ 51″	20′ 09″	20′ 09″	19′ 33″	18′ 21″	17′ 09

Observatory at Madras.—Hourly observations made during the Months of

$\alpha\left(1+\frac{H}{F}\right)=1'\times1{\cdot}00047=1'{\cdot}00047$. Declinometer No. I										
Sums	2713·0	2713·7	2715·9	2738·0	2777·3	2790·2	2755·7	2718·6	2678·6	2650
Means of 34 days ...	79·79	79·81	79·88	80·53	81·69	82·06	81·05	79·96	78·78	77·
Diurnal changes......	−0′·21	−0′·19	−0′·12	+0′·53	+1′·69	+2′·06	+1′·05	−0′·04	−1′·22	−2′·
Diurnal oscillation...	1′·85	1′·87	1′·94	2′·59	3′·75	4′·12	3′·11	2′·02	0′·84	0′·
Diurnal declination	54′ 53″ 0°	54′ 55″	54′ 59″	55′ 38″	56′ 47″	57′ 10″	56′ 09″	55′ 04″	53′ 53″	53′ 0
$\alpha\left(1+\frac{H}{F}\right)=1'\times1{\cdot}00034=1'{\cdot}00034$. Declinometer No. I										
Sums	1276·1	1276·0	1280·3	1308·7	1345·0	1358·2	1333·1	1303·6	1272·1	1249
Means of 33 days ...	38·67	38·67	38·80	39·66	40·76	41·15	40·40	39·50	38·55	37·
Diurnal changes ...	−0′·53	−0′·53	−0′·40	+0′·46	+1′·56	+1′·95	+1′·20	+0′·30	−0′·65	−1′·
Diurnal oscillation...	0′·81	0′·81	0′·94	1′·80	2′·90	3′·29	2′·54	1′·64	0′·69	0′·
Diurnal declination .	54′ 25″ 0°	54′ 25″	54′ 33″	55′ 25″	56′ 31″	56′ 54″	56′ 09″	55′ 15″	54′ 18″	53′ 3

TABLE A.

lonth of April, 1849. Latitude 16° 29′ 46″ N. Longitude 97° 45′ 30″ E.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
o from 14th to 21st, 53·17. α=2° 20′ 09″ East.											
355·6	358·1	363·0	368·8	371·7	371·4	368·6	365·5	364·9	6940·6	365·2	
50·80	51·16	51·86	52·69	53·10	53·06	52·66	52·21	52·13	991·53	52·18	2° 19′ 09″
−1′·4	−1′·0	−0′·3	+0′·5	+0′·9	+0′·9	+0′·5	0′·0	−0′·1			
0·0	0·4	1·1	1·9	2·3	2·3	1·9	1·4	1·3			
′ 45″	18′ 09″	18′ 51″	19′ 39″	20′ 03″	20′ 03″	19′ 39″	19′ 09″	19′ 03″			
ero from 16th to 21st, 119·58. α=2° 20′ 19″ East.											
582·2	584·5	589·5	595·5	598·4	596·6	592·8	589·9	588·9	11241·7	591·7	
16·44	116·90	117·90	119·10	119·68	119·32	118·56	117·98	117·78	2248·34	118·32	2° 18′ 51″
−1′·9	−1′·4	−0′·4	+0′·8	+1′·4	+1′·0	+0′·3	−0′·3	−0′·5			
0·0	0′·5	1′·5	2′·7	3′·3	2′·9	2′·2	1′·6	1′·4			
′ 47″	17′ 27″	18′ 27″	19′ 39″	20′ 15″	19′ 51″	19′ 09″	18′ 33″	18′ 21″			

August and September, 1849. Latitude 13° 04′ 09″ N. Longitude 80° 16′ 00″ E.

ero from August 22nd to September 29th, 81·05. α=0° 56′ 09″ East.											
653·4	2682·8	2712·9	2742·4	2745·1	2733·9	2725·2	2718·8	2716·6	51682·1	2719·9	
78·04	78·91	79·79	80·66	80·74	80·41	80·15	79·86	79·90	1520 05	80·00	0° 55′ 96″
1′·96	−1′·09	−0′·21	+0′·16	+0′·74	+0′·41	+0′·15	−0′·04	−0′·10			
0′·10	0′·97	1′·85	2′·72	2′·80	2′·47	2′·21	2′·02	1′·96			
′ 08″	53′ 07″	54′ 53″	55′ 46″	55′ 50″	55′ 31″	55′ 15″	55′ 04″	55′ 00″			
o from August 22nd to September 29th, 40·40. α=0° 56′ 09″ East.											
254·2	1278·7	1304·8	1319·8	1312·3	1293·6	1282·4	1271·4	1266·9	24586·6	1294·2	
38·01	38·75	39·54	39·99	39·77	39·20	38·86	38·53	38·39	745·06	39·20	
1′·09	−0′·45	+0′·34	+0′·79	+0′·57	0′·00	−0′·34	−0′·67	−0′·81			
0′·25	0′·89	1′·68	2′·13	1′·91	1′·34	1′·00	0′·67	0′·53			
′ 52″	54′ 30″	55′ 17″	55′ 44″	55′ 31″	54′ 57″	54′ 37″	54′ 17″	54′ 08″			

TABLE

Observatory at Madras.—Hourly observations made during the Months of Augu

$\alpha\left(1+\frac{H}{F}\right)=1'\cdot0047\times1\cdot0004=1'\cdot0051.$ Declinometer No.

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	351·8	355·0	356·5	384·0	431·8	437·3	400·0	354·9	314·1	28
Means of 33 days ...	10·66	10·76	10·80	11·64	13·08	13·25	12·12	10·75	9·52	8
Diurnal changes ...	−0′·01	+0′·09	+0′·13	+0′·97	+2′·41	+2′·58	+1′·45	+0′·08	−1′·15	−2′
Diurnal oscillation...	2′·01	2′·11	2′·15	2′·99	4′·43	4′·60	3′·47	2′·10	0′·87	0′
Diurnal declination .	54′ 41″ 0°	54′ 47″	54′ 50″	55′ 40″	55′ 11″	57′ 17″	56′ 09″	54′ 47″	53′ 33″	52′

Observatory at Car Nicobar.—Hourly observations made during t

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot00047=1'\cdot00047.$ Declinometer No.

Sums	426·7	425·5	422·9	419·2	418·3	420·4	428·4	435·2	438·9	43
Means of 5 days ...	85·34	85·10	84·58	83·84	83·66	84·08	85·68	87·04	87·78	87
Diurnal changes......	−1′·00	−1′·24	−1′·76	−2′·50	−2′·68	−2′·26	−0′·66	+0′·70	+1′·44	+1′
Diurnal oscillation...	1′·68	1′·44	0′·92	0′·18	0′·00	0′·42	2′·02	3′·38	4′·12	4′
Diurnal declination .	51′ 39″ +1°	51′ 25″	50′ 53″	49′ 09″	49′ 58″	50′ 23″	51′ 59″	53′ 21″	54′ 07″	54′

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot00034=1'\cdot00034.$ Declinometer No.

Sums	250·0	249·0	247·2	243·2	242·8	244·7	203·0	257·6	261·4	26
Means of 5 days ...	50·00	49·80	49·44	48·64	48·56	48·94	50·75	51·52	52·28	5
Diurnal changes ...	−0′·83	−1′·03	−1′·39	−2′·19	−2′·27	−1′·89	−0′·08	+0′·69	+1′·45	+1
Diurnal oscillation...	1′·44	1′·24	0′·88	0′·08	0′·00	0′·38	2′·19	2′·96	3′·72	3′
Diurnal declination .	51′ 50″ +1°	51′ 38″	51′ 16″	50′ 28″	50′ 23″	50′ 46″	52′ 35″	53′ 21″	54′ 07″	54′

$\alpha\left(1+\frac{H}{F}\right)=1'\cdot004\times1\cdot0004=1'\cdot004.$ Declinometer No.

Sums	505·6	504·9	502·8	499·3	499·4	503·3	510·2	517·0	519·3	51
Means of 5 days ...	101·12	100·98	100·56	99·86	99·88	100·66	102·04	103·40	103·86	10
Diurnal changes ...	−1′·20	−1′·34	−1′·76	−2′·46	−2′·44	−1′·66	−0′·28	+1′·08	+1′·54	+1
Diurnal oscillation...	1′·26	1′·12	0′·70	0′·00	0′·02	0′·80	2′·18	3′·54	4′·00	4
Diurnal declination .	51′ 04″ +1°	50′ 56″	50′ 31″	49′ 49″	49′ 50″	50′ 37″	51′ 59″	53′ 21″	53′ 47″	53′

BLE A.

d September, 1849. Latitude 13° 04′ 09″ N. Longitude 80° 16′ 00″ E. (*Continued.*)

from August 22nd to September 29th, 12·12. α=0·56′ 09″ East.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
87·2	308·4	341·0	364·3	365·5	346·8	338·8	333·2	332·7	6688·8	351·9	
8·70	9·35	10·33	11·04	11·08	10·51	10·27	10·10	10·08	202·69	10·67	
1′·97	−1′·32	−0′·34	+0′·37	+0′·41	−0′·16	−0′·40	−0′·57	−0′·59			
0′·05	0′·70	1′·68	2′·39	2′·43	1′·86	1′·62	1′·45	1′·43			
′ 44″	53′ 23″	54′ 22″	55′ 04″	55′ 07″	54′ 32″	54′ 18″	54′ 08″	54′ 07″			

onth of February 1849. Latitude 9° 10′ 12″ N. Longitude 92° 48′ 23″ N.

ero from 6th to 10th of February, 87·04. α=1° 53′ 21″·2 East.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
40·9	442·0	440·2	438·3	436·1	432·2	433·6	432·8	432·0	8203·2	431·7	
8·18	88·40	88·04	87·66	87·22	86·44	86·72	86·56	86·40	1640·64	86·34	1° 52′ 39″
1′·84	+2′·06	+1′·70	+1′·32	+0′·88	+0′·10	+0′·38	+0′·22	+0′·06			
4′·52	4′·74	4′·38	4′·00	3′·56	2′·78	3′·06	2′·90	2′·74			
′ 29″	54′ 43″	54′ 21″	53′ 58″	53′ 31″	52′ 45″	53′ 02″	52′ 52″	52′ 43″			

ero from February 6th to 10th, 51·52. α=1° 53′ 21″ East.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
62·7	263·3	261·3	259·0	256·8	252·4	254·3	254·0	253·4	4777·8	254·1	
2·54	52·66	52·26	51·80	51·36	50·48	50·86	50·80	50·68	965·71	50·83	1° 52′ 40″
1′·71	+1′·83	+1′·43	+0′·97	+0′·53	−0′·35	+0′·03	−0′·03	−0′·15			
3′·98	4′·10	3′·70	3′·24	2′·80	1′·92	2′·30	2′·24	2′·12			
′ 22″	54′ 29″	54′ 05″	53′ 38″	53′ 11″	51′ 19″	52′ 41″	52′ 38″	52′ 31″			

ero from February 6th to 10th, 103·40. α=1° 53′ 21″ East.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
0·4	520·4	519·1	516·8	514·6	408·9	410·1	409·8	409·4	9311·1	511·3	
4·08	104·08	103·82	103·36	102·92	102·23	102·53	102·45	102·35	1944·14	102·32	1° 52′ 16″
1′·76	+1′·76	+1′·50	+1′·04	+0′·60	−0′·09	+0′·21	+0′·13	+0′·03			
4′·22	4′·22	3′·96	3′·50	3′·06	2′·37	2′·67	2′·59	2′·49			
′ 03″	54′ 02″	53′ 46″	53′ 19″	52′ 52″	52′ 11″	52′ 29″	52′ 24″	52′ 18″			

TABLE

Observatory at Samboangan.—Hourly observations made during th

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.

$\alpha\left(1+\frac{H}{F}\right)=1'\times1{\cdot}000204+1'{\cdot}000204.$ Declinometer No.

	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	527·0	527·3	527·5	530·4	532·4	528·6	521·0	514·0	512·8	508
Means of 6 days ...	87·83	87·88	87·92	88·40	88·73	88·10	86·83	85·67	85·47	84·
Diurnal changes ...	+1′·15	+1′·20	+1′·24	+1′·72	+2′·05	+1′·42	+0′·15	−1′·01	−1′·21	−1′·
Diurnal oscillation...	3′·01	3′·06	3′·10	3′·58	3′·91	3′·28	2′·01	0′·85	0′·65	0′·
Diurnal declination .	17′ 34″ +1°	17′ 37″	17′ 39″	18′ 08″	18′ 28″	17′ 50″	16′ 34″	15′ 24″	15′ 12″	14′ 3

$\alpha\left(1+\frac{H}{F}\right)=1'\times1{\cdot}000250=1'{\cdot}00025.$ Declinometer No. I

	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	316·3	316·6	316·4	319·5	318·4	259·2	256·4	303·4	303·5	29
Means of 6 days ...	52·72	52·77	52·73	53·25	53·07	51·84	51·28	50·57	50·58	49·
Diurnal changes ...	+1′·28	+1′·33	+1′·29	+1′·81	+1′·63	+0′·40	−0′·16	−0′·87	−0′·86	−1′·
Diurnal oscillation...	3′·22	3′·27	3′·23	3′·75	3′·57	2′·34	1′·78	1′·07	1′·08	0′·
Diurnal declination .	17′ 33″ +1°	17′ 36″	17′ 34″	18′ 05″	17′ 54″	16′ 40″	16′ 07″	15′ 24″	15′ 25″	14′

Observatory at Penang.—Hourly observations made during t

$\alpha\left(1+\frac{H}{F}\right)=1'\times1{\cdot}00047=1'{\cdot}00047.$ Declinometer No.

Sums	434·1	434·0	432·2	427·3	424·0	427·5	435·7	444·0	443·9	44
Means of 5 days ...	86·82	86·80	86·44	85·46	84·80	85·50	87·14	88·80	88·78	8
Diurnal changes ...	−0′·76	−0′·78	−1′·14	−2′·12	−2′·78	−2′·08	−0′·44	+1′·22	+1′·20	+2
Diurnal oscillation...	2′·02	2′·00	1′·64	0′·66	0′·00	0′·70	2′·34	4′·00	3′·98	4
Diurnal declination .	47′ 47″ +1°	47′ 46″	47′ 24″	46′ 25″	45′ 46″	46′ 28″	48′ 06″	49′ 46″	49′ 44″	50′

$\alpha\left(1+\frac{H}{F}\right)=1'\times1{\cdot}00034=1'{\cdot}00034.$ Declinometer N

Sums	258·6	258·7	256·7	251·7	247·3	250·7	258·9	264·0	262·8	2
Means of 5 days ...	51·72	51·74	51·34	50·34	49·46	50·14	51·78	52·80	52·56	5
Diurnal changes ...	−0′·16	−0′·14	−0′·54	−1′·54	−2′·42	−1′·74	−0′·10	+0′·92	+0′·68	+1
Diurnal oscillation...	2′·26	2′·28	1′·88	0′·88	0′·00	0′·68	2′·32	3′·34	3′·10	4
Diurnal declination .	48′ 02″ +1°	48′ 04″	47′ 40″	46′ 40″	45′ 47″	46′ 28″	48′ 06″	49′ 07″	48′ 53″	50′

ABLE A.

Month of May, 1848. Latitude 6° 54′ 20″ N. Longitude 122° 13′ 45″ E.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
Zero from 25th to 31st, 85·67. α=1° 15′ 24″ East.											
509·9	511·2	512·3	516·3	520·3	520·9	521·4	520·1	519·5	9881·8	520·1	
84·98	85·20	85·38	86·05	86·72	86·82	86·90	86·68	86·58	1646·96	86·68	1° 16′ 25″
−1′·70	−1′·48	−1′·30	−0′·63	+0′·04	+0′·14	+0′·22	0′·00	−0′·10			
0′·16	0′·38	0′·56	1′·23	1′·90	2′·00	2′·08	1′·86	1′·76			
4′ 43″	14′ 56″	14′ 07″	15′ 47″	16′ 27″	16′ 33″	16′ 38″	16′ 25″	16′ 19″			
Zero from 25th to 31st, 50·57. α=1° 15′ 24″ East.											
297·9	300·9	301·6	306·6	310·0	310·0	309·9	308·7	308·9	5761·2	308·6	
49·65	50·15	50·27	51·10	51·67	51·67	51·65	51·45	51·48	977·40	51·44	1° 16′ 16″
−1′·79	−1′·29	−1′·17	−0′·34	+0′·23	+0′·23	+0′·21	+0′·01	+0′·04			
0′·15	0′·65	0′·77	1′·60	2′·17	2′·17	2′·15	1′·95	1′·98			
14′ 29″	14′ 59″	15′ 06″	15′ 56″	16′ 30″	16′ 30″	16′ 29″	16′ 17″	16′ 19″			

Month of January, 1849. Latitude 5° 25′ 36″ N. Longitude 100° 24′ 38″ E.

Zero from the 22nd to the 26th, 78·14. α=1° 48′ 06″.											
448·3	446·7	444·9	443·1	438·5	436·0	437·1	437·6	436·9	8320·3	437·8	
89·66	89·34	88·98	88·62	87·70	87·20	87·42	87·52	87·38	1664·06	87·58	1° 48′ 32″
+2′·08	+1′·76	+1′·40	+1′·04	+0′·12	−0′·38	−0′·16	−0′·06	−0′·20			
4′·86	4′·54	4′·18	3′·82	2′·90	2′·40	2′·62	2′·72	2′·58			
50′ 37″	50′ 18″	49′ 56″	49′ 35″	48′ 40″	48′ 10″	48′ 24″	48′ 29″	48′ 20″			
Zero from the 22nd to the 26th, 51·78. α=1° 48′ 06″.											
268·1	266·4	264·5	262·4	258·3	253·5	256·7	256·5	255·6	4919·9	259·0	
53·62	53·28	52·90	52·48	51·66	50·70	51·34	51·30	51·12	983·98	51·88	
+1′·74	+1′·40	+1′·02	+0′·60	−0′·22	−1′·18	−0′·54	−0′·58	−0′·76			
4′·16	3′·82	3′·44	3′·02	2′·20	1′·24	1′·88	1′·84	1′·66			
49′ 56″	49′ 36″	49′ 13″	48′ 48″	47′ 59″	47′ 01″	47′ 40″	47′ 37″	47′ 26″			

TABLE A

Observatory at Penang.—Hourly observations made during the

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.

$\alpha\left(1+\frac{H}{F}\right)=1'\cdot004\times1\cdot0004=1'\cdot004.$ Declinometer No. II

Sums	516·2	517·3	514·5	508·7	506·5	509·2	518·8	524·6	527·3	532·
Means of 5 days	103·24	103·46	102·90	101·74	101·30	101·84	103·76	104·92	105·46	106·5
Diurnal changes	−1'·23	−1'·01	−1'·57	−2'·73	−3'·17	−2'·63	−0'·71	+0'·45	+0'·99	+2'·1
Diurnal oscillation	1'·94	2'·16	1'·60	0'·44	0'·00	0'·54	2'·46	3'·62	4'·16	5'·2
Diurnal declination	47' 35" +1°	47' 48"	47' 14"	46' 05"	45' 38"	46' 11"	48' 06"	49' 16"	49' 48"	50' 55'

Observatory at Pulo Dinding.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot0005=1'\cdot0005.$ Declinometer No. I.

Sums	266·7	265·7	264·8	262·8	257·6	255·6	260·2	268·2	272·6	276·
Means of 3 days	88·90	88·57	88·27	87·60	85·87	85·20	86·73	89·40	90·87	92·0
Diurnal changes	−0'·82	−1'·15	−1'·45	−2'·12	−3'·85	−4'·52	−2'·99	−0'·32	+1'·15	+2'·31
Diurnal oscillation	3'·70	3'·37	3'·07	2'·40	0'·67	0'·00	1'·53	4'·20	5'·67	6'·83
Diurnal declination	48' 04" +1°	47' 44"	47' 26"	46' 46"	45' 02"	44' 22"	45' 54"	48' 34"	50' 02"	51' 12"

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000445=1'\cdot000445.$ Declinometer No. II.

Sums	140·4	139·0	138·2	135·8	130·6	128·2	133·3	141·6	145·7	147·5
Means of 3 days	46·80	46·33	46·07	45·27	43·53	42·73	44·43	47·20	48·57	49·17
Diurnal changes	−0'·48	−0'·95	−1'·21	−2'·01	−3'·75	−4'·55	−2'·85	−0'·08	+1'·29	+1'·89
Diurnal oscillation	4'·07	3'·60	3'·34	2'·54	0'·80	0'·00	1'·70	4'·47	5'·84	6'·44
Diurnal declination	48' 10" +1°	47' 42"	47' 26"	46' 38"	44' 54"	44' 06"	45' 48"	48' 34"	49' 56"	50' 32"

$\alpha\left(1+\frac{H}{F}\right)=1'\cdot004\times1\cdot0006=1'\cdot0046.$ Declinometer No. III.

Sums	301·8	301·2	300·6	297·6	293·4	292·6	298·1	306·7	311·1	314·0
Means of 3 days	100·60	100·40	100·20	99·20	97·80	97·53	99·37	102·23	103·70	104·67
Diurnal changes	−1'·31	−1'·51	−1'·71	−2'·71	−4'·11	−4'·38	−2'·54	+0'·32	+1'·79	+2'·76
Diurnal oscillation	3'·07	2'·87	2'·67	1'·67	0'·27	0'·00	1'·84	4'·70	6'·17	7'·14
Diurnal declination	46' 56" +1°	46' 44"	46' 32"	45' 32"	44' 08"	43' 52"	45' 42"	48' 34"	50' 02"	51' 00'

Table A.

Month of May, 1848. Latitude 6° 54′ 20″ N. Longitude 122° 13′ 45″ E.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
Zero from the 22nd to the 26th, 103·76. α=1° 48′ 06″.											
534·6	531·7	530·6	529·1	525·8	523·7	524·6	525·1	523·5	9924·7	522·3	
106·92	106·34	106·12	105·82	105·16	104·74	104·92	105·02	104·70	1984·94	104·47	
+2′·45	+1′·87	+1′·65	+1′·35	+0′·69	+0′·27	+0′·45	+0′·55	+0′·23			
5′·62	5′·04	4′·82	4′·52	3′·86	3′·44	3′·62	3′·72	3′·40			
51′ 16″	50′ 41″	50′ 28″	50′ 10″	49′ 30″	49′ 05″	49′ 16″	49′ 22″	49′ 02″			

Month of January, 1849. Latitude 4° 12′ 48″ N. Longitude 100° 32′ 52″ E.

Zero from the 11th to the 13th, 89·4. α=1° 48′ 34″.											
277·3	278·0	277·8	275·5	273·0	271·0	271·5	270·4	269·4	5114·2	269·2	
92·43	92·67	92·60	91·83	91·00	90·33	90·50	90·13	89·80	1704·73	39·72	1° 48′ 53″
+2′·71	+2′·95	+2′·88	+2′·11	+1′·28	+0′·61	+0′·78	+0′·41	+0′·08			
7′·23	7′·47	7′·40	6′·63	5′·80	5′·13	5′·30	4′·93	4′·60			
51′ 36″	51′ 50″	51′ 46″	51′ 00″	50′ 10″	49′ 30″	49′ 40″	49′ 18″	48′ 58″			
Zero from the 11th to the 13th, 47·20. α=1° 48′ 34″.											
148·7	150·4	150·5	148·6	146·0	143·4	143·8	142·1	141·3	2695·1	141·8	
49·57	50·13	50·17	49·53	48·67	48·70	47·93	47·37	47·10	898·37	47·28	
+2′·29	+2′·85	+2′·89	+2′·25	+1′·39	+0′·52	+0′·65	+0′·09	−0′·18			
6′·84	7′·40	7′·44	6′·80	5′·94	5′·07	5′·20	4′·64	4′·37			
50′ 56″	51′ 30″	51′ 32″	50′ 54″	50′ 02″	49′ 10″	49′ 18″	48′ 44″	48′ 28″			
Zero from the 11th to the 13th, 102·23. α=1° 48′ 34″.											
315·8	316·5	315·8	312·7	309·4	306·2	306·3	305·0	304·0	5808·8	305·7	
105·27	105·50	105·27	104·23	103·13	102·07	102·10	101·67	101·33	1936·27	101·91	
+3′·36	+3′·59	+3′·36	+2′·32	+1′·22	+0′·16	+0′·19	−0′·24	−0′·58			
7′·74	7′·97	7′·74	6′·70	5′·60	4′·54	4′·57	4′·14	3′·80			
51′ 36″	52′ 02″	51′ 36″	50′ 34″	49′ 28″	48′ 24″	48′ 26″	48′ 00″	47′ 40″			

TABLE A

Observatory at Sarawak.—Hourly observations made during the

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000158=1'\cdot000158.$ Declinometer No. I.

Sums	2229·2	2234·8	2240·6	2245·4	2246·4	2251·4	2264·4	2283·1	2269·0	2243·8	2223·3	2209·7	2200·
Means of 26 days ...	85·74	85·95	86·18	86·36	86·40	86·59	87·09	87·81	87·27	86·30	85·51	84·99	84·6
Diurnal changes ...	−0'·03	+0'·18	+0'·41	+0'·59	+0'·63	+0'·82	+1'·32	+2'·04	+1'·50	+0'·53	−0'·26	−0'·78	−1'·1
Diurnal oscillation...	1'·17	1'·38	1'·61	1'·79	1'·83	2'·02	2'·52	3'·24	2'·70	1'·73	0'·96	0'·42	0'·0
Diurnal declination .	09' 06" +1°	09' 19"	09' 33"	09' 44"	09' 46"	09' 57"	10' 27"	11' 11"	10' 38"	09' 40"	08' 53"	08' 21"	08' 01'

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000139=1'\cdot000139.$ Declinometer No. II.

Sums	1364·1	1369·1	1374·1	1377·0	1377·0	1380·7	1393·0	1411·1	1395·8	1373·4	1358·0	1351·8	1295·
Means of 26 days ...	52·47	52·66	52·85	52·96	52·96	53·10	53·58	54·27	53·68	52·82	52·23	51·99	51·8
Diurnal changes ...	−0'·28	−0'·09	+0'·10	+0'·21	+0'·21	+0'·35	+0'·83	+1'·52	+0'·93	+0'·07	−0'·52	−0'·76	−0'·9
Diurnal oscillation .	0'·65	0'·84	1'·03	1'·14	1'·14	1'·28	1'·76	2'·45	1'·86	1'·00	0'·41	0'·17	0'·0
Diurnal declination .	09' 19" +1°	09' 30"	09' 42"	09' 48"	09' 48"	09' 57'	10' 26"	11' 07"	10' 32"	09' 40"	09' 05"	08' 50"	08' 40'

Hourly observations made during

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000158=1'\cdot000158.$ Declinometer No. I.

Sums	2342·0	2345·6	2353·9	2358·7	2364·4	2368·3	2381·6	2399·3	2384·0	2358·9	2340·6	2328·1	2322·
Means of 27 days ...	86·74	86·87	87·18	87·36	87·57	87·71	88·21	88·86	88·30	87·37	86·69	86·23	86·0
Diurnal changes......	−0'·20	−0'·07	+0'·24	+0'·42	+0'·63	+0'·77	+1'·27	+1'·92	+1'·36	+0'·43	−0'·25	−0'·71	−0'·9
Diurnal oscillation...	0'·80	0'·93	1'·24	1'·42	1'·63	1'·77	2'·27	2'·92	2'·36	1'·43	0'·75	0'·29	0'·0
Diurnal declination .	09' 02' +1°	09' 10"	09' 29"	09' 39"	09' 52"	10' 00"	10' 30"	11' 09"	10' 36"	09' 40"	09' 59"	09' 32"	08' 19'

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000139=1'\cdot000139.$ Declinometer No. II.

Sums	1425·1	1426·0	1450·9	1434·7	1436·2	1435·6	1442·6	1455·7	1387·4	1416·8	1400·0	1399·1	1395·
Means of 25 days ...	57·00	57·04	58·04	57·39	57·45	57·42	57·70	58·23	57·81	56·67	56·00	55·96	55·8
Diurnal changes......	−0'·07	−0'·03	+0'·97	+0'·32	+0'·38	+0'·35	+0'·63	+1'·16	+0'·74	−0'·40	−1'·07	−1'·11	−1'·2
Diurnal oscillation...	1'·19	1'·23	2'·23	1'·58	1'·64	1'·61	1'·89	2'·42	2'·00	0'·86	0'·19	0'·15	0'·0
Diurnal declination .	9' 00" +1°	10' 02"	11' 02"	10' 23"	10' 27"	10' 25"	10' 42"	11' 14"	10' 48"	9' 40"	9' 00"	8' 57"	8' 49

ABLE A.

onth of June, 1846. Latitude 1° 33′ 54″ N. Longitude 110° 29′ 00″ E.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Declin.
ero from the 1st to the 30th, 86·30. α=1° 09′ 40″ East.													
198·7	2205·9	2212·7	2221·4	2222·4	2217·2	2220·8	2217·6	2219·8	2221·4	2222·8	53522·7	2230·0	
84·57	84·84	85·10	85·44	85·48	85·28	85·42	85 29	85·38	85·44	85·49	2058·57	85·77	1° 09′ 08″
1′·20	−0′·93	−0′·67	−0′·33	−0′·29	−0′·49	−0′·35	−0′·48	−0′·39	−0′·33	−0′·28			
0′·00	0′·27	0′·53	0′·87	0′·91	0′·71	0′·85	0′·72	0′·81	0′·87	0′·92			
′ 56″	09′ 12″	08′ 28″	08′ 48″	08′ 51″	08′ 39″	08′ 47″	08′ 39″	08′ 45″	08′ 48″	08′ 51″			
ero from the 1st to the 30th, 52·82. α=1° 09′ 40″ East.													
299·4	1363·7	1371·6	1326·5	1382·3	1373·0	1370·2	1361·7	1363·6	1362·2	1362·1	32757·0	1371·7	
51·98	52·45	52·75	53·06	53·17	52·81	52·70	52·37	52·45	52·39	52·39	1265·91	52·75	1° 09′ 40″
0′·77	−0′·30	0′·00	+0′·31	+0′·42	+0′·06	−0′·05	−0′·38	−0′·30	−0′·36	−0′·36			
0′·16	0′·63	0′·93	1′·24	1′·35	0′·99	0′·88	0′·55	0′·63	0′·57	0′·57			
′ 47″	09′ 18″	08′ 36″	09′ 54″	10′ 01″	09′ 39″	09′ 33″	09′ 13″	09′ 18″	09′ 14″	09′ 14″			

he Month of July 1846.

Zero from the 1st to the 31st, 87·37. α=1° 09′ 40″ East.													
320·5	2323·4	2332·1	2341·7	2349·6	2341·5	2337·6	2334·9	2334·3	2335·3	2336·4	56335·1	2347·1	
85·94	86·05	86·37	86·73	87·02	86·72	86·58	86·48	86·46	86·49	86·53	2086·48	86·94	1° 09′ 14″
-1′·00	−0′·89	−0′·57	−0′·21	+0′·08	−0′·22	−0′·36	−0′·46	−0′·48	−0′·45	−0′·41			
0′·00	0′·11	0′·43	0′·79	1′·08	0′·78	0′·64	0′·54	0′·52	0′·55	0′·59			
8′ 14″	08′ 21″	08′ 40″	09′ 02″	09′ 19″	09′ 01″	08′ 53″	08′ 47″	08′ 45″	08′ 47″	08′ 50″			
Zero from the 1st to the 31st, 56·67. α=1° 09′ 40″ East.													
1339·4	1404·3	1370·2	1437·0	1390·0	1437·6	1429·9	1428·0	1428·9	1425·9	1424·7	34011·4	1426·4	
55·81	56·17	57·09	57·48	57·92	57·50	57·20	57·12	57·16	57·09	56·99	1369·61	57·07	1° 9′ 16″
-1′·26	−0′·90	+0′·02	+0′·41	+0′·85	+0′·43	+0′·13	+0′·05	+0′·09	−0′·03	−0′·08			
0′·00	0′·36	1′·28	1′·67	2′·11	1′·69	1′·39	1′·31	1′·35	1′·23	1′·18			
8′ 48″	9′ 10″	10′ 05″	10′ 29″	10′ 55″	10′ 30″	10′ 12″	10′ 07″	10′ 09″	10′ 02″	9′ 59″			

Table A

Observatory at Sarawak.—Hourly observations made during the

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1{\cdot}000158=1'{\cdot}000158.$ Declinometer No. I

Sums	1652·4	1653·2	1655·2	1659·5	1662·3	1665·8	1679·1	1699·1	1688·8	1661·8	1645·1	1632·4	1630·
Means of 19 days ...	86·97	87·01	87·12	87·34	87·49	87·67	88·37	89·43	88·88	87·46	86·58	85·92	85·
Diurnal changes ...	−0′·24	−0′·20	−0′·09	+0′·13	+0′·28	+0′·46	+1′·16	+2′·22	+1′·67	+0′·25	−0′·23	−1′·29	−1′·4
Diurnal oscillation...	1′·18	1′·22	1′·33	1′·55	1′·70	1′·88	2′·58	3′·64	3′·09	1′·67	1′·19	0′·13	0′·0
Diurnal declination .	09′ 11″ +1°	09′ 13″	09′ 20″	09′ 33″	09′ 42″	09′ 52″	10′ 34″	11′ 38″	11′ 05″	09′ 40″	09′ 11″	08′ 08″	08′ 0

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1{\cdot}000139=1'{\cdot}000139.$ Declinometer No. II

Sums	1146·5	1146·7	1149·7	1151·4	1152·8	1158·0	1171·1	1187·6	1179·2	1155·3	1143·3	1135·0	1133
Means of 19 days ...	60·34	60·35	60·51	60·60	60·67	60·95	61·64	62·51	62·06	60·81	60·17	59·74	59·
Diurnal changes ...	−0′·54	−0′·53	−0′·37	−0′·28	−0′·21	+0′·07	+0′·76	+1′·63	+1′·18	−0′·07	−0′·71	−1′·14	−1′·
Diurnal oscillation...	0′·68	0′·69	0′·85	0′·94	1′·01	1′·29	1′·98	2′·85	2′·40	1′·15	0′·51	0′·08	0′·
Diurnal declination .	09′ 12″ +1°	09′ 12″	09′ 22″	09′ 27″	09′ 32″	09′ 48″	10′ 30″	11′ 22″	10′ 55″	09′ 40″	10′ 02″	08′ 36″	08′ 3

Observatory at Keemah.—Hourly observations made during th

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1{\cdot}000278=1'{\cdot}000278.$ Declinometer No.

Sums	......	......	......	839·6	838·1	840·1	840·3	852·6	761·2	831·6	820·3	730·1	645
Means of 10 days ...	......	......	......	83·96	83·81	84·01	84·03	85·26	84·58	83·16	82·03	81·12	80·
Diurnal changes ...	......	......	......	+0′·98	+0′·83	+1′·03	+1′·05	+2′·28	+1′·60	+0′·18	−0′·95	−1′·86	−2′·
Diurnal oscillation...	......	......	......	3′·26	3′·11	3′·31	3′·33	4′·56	3′·88	2′·46	1′·33	0′·42	0′·
Diurnal declination .	......	......	......	40′ 35″ +1	40′ 26″	40′ 38″	40′ 39″	41′ 53″	41′ 12″	39′ 47″	38′ 39″	37′ 45″	37′ 1

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1{\cdot}000222=1'{\cdot}000222.$ Declinometer No. I

Sums	......	......	......	520·3	518·0	520·4	522·4	528·2	471·7	512·2	504·5	451·2	450
Means of 10 days ...	......	......	......	52·03	51·80	52·04	52·24	52·82	52·41	51·22	50·45	50·13	50·
Diurnal changes ...	......	......	.....	+0′·56	+0′·33	+0′·57	+0′·77	+1′·35	+0′·94	−0′·25	−1′·02	−1′·34	−1′·
Diurnal oscillation...	......	......	......	2′·01	1′·78	2′·02	2′·22	2′·80	2′·39	1′·20	0′·43	0′·11	0′·
Diurnal declination .	......	......	......	40′ 36″ +1°	40′ 22″	40′ 36″	40′ 48″	41′ 23″	40′ 58″	39′ 47″	39′ 01″	38′ 42″	38′ 3

ABLE A.

onth of August, 1846. Latitude 1° 33′ 54″ N. Longitude 110° 29′ 00″ E.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Declin.
ero from the 1st to the 22nd, 87·46. α=1° 09′ 40″ East.													
634·3	1642·4	1649·4	1661·7	1665·3	1657·7	1569·7	1567·0	1569·7	1567·2	1564·8	39333·9	1657·0	
86·02	86·44	86·81	87·46	87·65	87·25	87·21	87·06	87·21	87·07	86·93	2087·87	87·21	1° 09′ 25″
-1′·19	−0′·77	−0′·40	+0′·25	+0′·44	+0′·04	0′·00	−0′·15	0′·00	−0′·14	0′·28			
0′·23	0′·65	1′·02	1′·67	1′·86	1′·46	1′·42	1′·27	1′·42	1′·28	1′·14			
′ 14″	08′ 39″	09′ 01″	09′ 40″	09′ 51″	09′ 27″	09′ 25″	09′ 16″	09′ 25″	09′ 17″	09′ 08″			
ero from the 1st to the 22nd, 60·81. α=1° 09′ 40″ East.													
141·5	1153·1	1162·1	1176·5	1179·3	1169·0	1098·2	1092·9	1094·7	1090·6	1087·3	27455·3	1157·0	
60·08	60·69	61·16	61·92	62·07	61·53	61·01	60·72	60·82	60·59	60·41	1462·59	60·88	1° 09′ 44″
-0′·80	−0′·19	+0′·28	+1′·14	+1′·19	+0′·65	+0′·13	−0′·16	−0′·06	−0′·29	−0′·47			
0′·42	1′·03	1′·50	2′·36	2′·41	1′·87	1′·35	1′·06	1′·16	0′·93	0′·75			
′ 56″	09′ 33″	10′ 01″	10′ 53″	10′ 56″	10′ 23″	09′ 52″	09′ 35″	09′ 41″	09′ 27″	09′ 16″			

onth of June, 1848. Latitude 1° 21′ 55″ N. Longitude 125° 07′ 59″ E.

ero from the 21st of June to July 1st, 83·16. α=1° 39′ 47″ East.													
31·1	738·1	824·4	828·2	829·3	829·2	830·6	829·4	828·6	……	……	15268·4	830·0	
81·23	82·01	82·44	82·82	82·93	82·92	83·06	82·94	82·86	……	……	1575·87	82·98	1° 39′ 36″
-1′·75	−0′·97	−0′·54	−0 ·16	−0′·05	−0′·06	+0′·08	−0′·04	−0′·12	……	……			
0′·53	1′·31	1′·74	2′·12	2′·23	2′·22	2′·36	2′·24	2′·16	……	……			
7′ 51″	38′ 38′	39′ 04″	39′ 27″	39′ 33″	39′ 33″	39′ 41″	39′ 34″	39′ 29″	……	……			
ero from the 21st of June to July 1st, 51·22. α=1° 39′ 47″ East.													
07·2	512·1	514·8	517·1	517·7	516·1	515·6	514·6	511·5	……	……	9625·8	514·6	
0·72	51·21	51·48	51·71	51·77	51·61	51·56	51·46	51·15	……	……	977·83	51·47	1° 40′ 02″
0′·75	−0′·26	+0′·01	+0′·24	+0′·30	+0′·14	+0′·09	−0′·01	−0′·32	……	……			
0′·70	1′·19	1′·46	1′·69	1′·75	1′·59	1′·54	1′·44	1′·13	……	……			
′ 17″	39′ 46″	40′ 03″	40′ 16″	40′ 20″	40′ 10″	40′ 07″	40′ 01″	39′ 43″	……	……			

Table A

Observatory at Keemah.—Hourly observations made during the Month o

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.

$\alpha\left(1+\ \right)=1'\cdot004\times1\cdot000306=1'\cdot0043.$ Declinometer No. I.

Sums	1028·1	1026·4	1028·0	1028·6	1037·0	927·0	1020·0	1013·1	910·2	910·
Means of 10 days ...	102·81	102·64	102·80	102·86	103·70	103·00	102·00	101·31	101·13	101·1
Diurnal changes ...	+0'·16	−0'·01	+0'·15	+0'·21	+1'·05	+0'·35	−0'·65	−1'·34	−1'·52	−1'·4
Diurnal oscillation...	1'·68	1'·51	1'·67	1'·73	2'·57	1'·87	0'·87	0'·18	0'·00	0'·
Diurnal declination .	40' 36" +1°	40' 25"	40' 35"	40' 39"	41' 29"	40' 47"	39' 47"	39' 06"	38' 55"	38' 5

Observatory at Pulo Peesang.—Hourly observations made during th

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000158=1'\cdot000158.$ Declinometer No.

Sums	......	78·9	151·9	185·8	179·8	180·8	185·4	187·4	193·6	200
Means of 5 days ...	......	39·45	37·47	37·16	35·96	36·16	37·08	37·48	38·72	40·
Diurnal changes ...	......	+0'·85	−1'·13	−1'·44	−2'·64	−2'·44	−1'·52	−1'·12	+0'·12	+1'·
Diurnal oscillation...	......	3'·29	1'·51	1'·00	0'·20	0'·00	0'·92	1'·32	2'·56	3'·
Diurnal declination .	......	33' 29" +1°	31' 46"	31' 12"	30' 24"	30' 12"	31' 07"	31' 31"	32' 45"	34' 0'

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000139=1'\cdot000139.$ Declinometer No. I

Sums	.....	87·0	177·0	217·8	212·5	213·4	217·6	218·8	221·3	22
Means of 5 days ...	......	43·50	44·25	43·56	42·50	42·68	43·52	43·76	44·26	44
Diurnal changes ...	......	−0'·72	+0'·03	−0'·66	−1'·72	−1'·54	−0'·70	−0'·46	+0'·04	+0'
Diurnal oscillation...	......	1'·00	1'·75	1'·06	0'·00	0'·18	1'·02	1'·26	1'·76	2'
Diurnal declination .	......	31' 08" +1°	31' 51"	31' 09"	30' 06"	30' 17"	31' 07"	31' 21"	31' 51"	32'

Observatory at Singapore.—Hourly observations made during t

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000315=1'\cdot000305.$ Declinometer No.

Sums	223·1	216·8	210·2	197·0	185·8	187·3	200·6	220·3	241·2	2
Means of 16 days ...	13·94	13·55	13·14	12·31	11·61	11·71	12·54	13·77	15·08	1
Diurnal changes ...	−0'·57	−0'·92	−1'·33	−2'·16	−2'·86	−2'·76	−1'·93	−0'·70	+0'·61	+1
Diurnal oscillation...	2'·33	1'·94	1'·53	0'·70	0'·00	0'·10	0'·93	2'·16	3'·47	4
Diurnal declination .	36' 53" +1°	36' 30"	36' 05"	35' 15"	34' 33"	34' 39"	35' 29"	36' 43"	38' 01"	38'

ABLE A.

June and July, 1848. Latitude 1° 21′ 55″. Longitude 125° 07′ 59″ E.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
Zero from the 21st of June to July 1st, 102·00. α=1° 89′ 47″ East.											
1019·5	1027·1	1031·4	1034·3	1034·4	1033·0	1031·7	1028·9	1025·8	19195·2	1026·4	
101·95	102·71	103·14	103·43	103·44	103·30	103·17	102·89	102·58	1950·05	102·65	1° 40′ 26″
−0′·70	+0′·06	+0′·49	+0′·78	+0′·79	+0·′65	+0′·52	+0′·24	−0′·07			
0′·82	1′·58	2′·01	2′·30	2′·31	2′·17	2′·04	1′·76	1′·45			
9′ 44″	40′ 30″	40′ 55″	41′ 13″	41′ 13″	41′ 05″	40′ 57″	40′ 40″	40′ 22″			

Month of January, 1846. Latitude 1° 27′ 53″ N. Longitude 103° 19′ 15″ E.

Zero from the 18th to the 22nd, 37·08. α=1° 31′ 07″ East.											
203·5	202·8	199·2	197·9	157·6	197·6	196·8	155·7	114·9	3165·0	193·1	
40·70	40·56	39·84	39·58	39·40	39·52	39·36	38·93	38·30	695·01	38·60	1° 32′ 30″
+2′·10	+1′·96	+1′·24	+0′·98	+0′·80	+0′·92	+0′·76	+0′·33	−0′·30			
4′·54	4′·40	3′·68	3′·42	3′·24	3′·36	3′·20	2′·77	2′·14			
34′ 44″	34′ 36″	33′ 53″	33′ 37″	33′ 26″	33′ 33″	33′ 24″	32′ 58″	32′ 20″			
Zero from the 18th to the 22nd. α=1° 31′ 07″ East.											
228·8	182·3	224·4	223·6	178·6	222·3	222·3	177·1	132·7	3582·2	221·0	
45·76	45·58	44·88	44·72	44·65	44·46	44·46	44·28	44·23	795·99	44·22	
+1′·54	+1′·36	+0′·66	+0′·50	+0′·43	+0′·24	+0′·24	+0′·06	+0′·01			
3′·26	3′·08	2′·38	2′·22	2′·15	1′·96	1′·96	1′·78	1′·73			
33′ 21″	33′ 11″	32′ 29″	32′ 19″	32′ 15″	32′ 03″	32′ 03″	31′ 53″	31′ 50″			

Month of November, 1848. Latitude 1° 18′ 32″ N. Longitude 103° 56′ 30″ E.

Zero from the 13th to the 30th, 12·54. α=1° 35′ 29″ East.											
269·3	266·0	266·8	255·4	245·9	245·6	243·4	239·0	232·8	4400·1	231·7	
16·83	16·63	16·68	15·96	15·37	15·35	15·21	14·94	14·55	275·02	14·47	1° 37′ 25″
+2′·36	+2′·16	+2′·21	+1′·49	+0′·90	+0′·88	+0′·74	+0′·47	+0′·08			
5′·22	5′·02	5′·07	4′·35	3′·76	3′·74	3′·60	3′·33	2′·94			
39′ 46″	39′ 34″	39′ 37″	38′ 54″	38′ 19″	38′ 18″	38′ 09″	37′ 53″	37′ 30″			

TABLE A.

Observatory at Singapore.—Hourly observations made during the Month

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$\alpha\left(1+\frac{H}{F}\right)=1'\times1{\cdot}000371=1'{\cdot}000371$. Declinometer No. II.										
Sums	796·8	791·7	784·1	771·9	758·6	755·0	769·8	791·1	813·2	827·3
Means of 16 days ...	49·80	49·48	49·01	48·24	47·41	47·19	48·11	49·44	50·83	51·71
Diurnal changes ...	−0'·55	−0'·87	−1'·34	−2'·11	−2'·94	−3'·16	−2'·24	−0'·91	+0'·48	+1'·36
Diurnal oscillation...	2'·61	2'·29	1'·82	1'·05	0'·22	0'·00	0'·92	2'·25	3'·64	4'·52
Diurnal declination .	37' 10" +1°	36' 51"	36' 23"	35' 37"	34' 49"	34' 34"	35' 29"	36' 49"	38' 12"	39' 05"
$\alpha\left(1+\frac{H}{F}\right)=1'{\cdot}0047\times1{\cdot}00037=1'{\cdot}004$. Declinometer No. III.										
Sums	1563·3	1557·0	1549·9	1536·4	1527·6	1526·2	1541·3	1560·8	1583·3	1594·8
Means of 16 days ...	97·71	97·31	96·87	96·03	95·48	95·39	96·33	97·55	98·96	99·68
Diurnal changes ...	−0'·54	−0'·94	−1'·38	−2'·22	−2'·77	−2'·86	−1'·92	−0'·70	+0'·71	+1'·43
Diurnal oscillation...	2'·32	1'·92	1'·48	0'·64	0'·09	0'·00	0'·94	2'·16	3'·57	4'·29
Diurnal declination .	36' 52" +1°	36' 28"	36' 01"	35' 11"	34' 38"	34' 33'	35' 29"	36' 39"	38' 07"	38' 50"
$\alpha\left(1+\frac{H}{F}\right)=1'{\cdot}0005\times1{\cdot}0003=1'{\cdot}0008$. Declinometer No IV.										
Sums	1558·4	1472·3	1463·0	1449·7	1429·3	1427·0	1439·7	1456·4	1473·8	1486·2
Means of 16 days ...	97·40	98·15	97·53	96·65	95·29	95·13	95·98	97·09	98·25	99·08
Diurnal changes ...	−0'·71	+0'·04	−0'·58	−1'·46	−2'·82	−2'·98	−2'·13	−1'·02	+0'·14	+0'·97
Diurnal oscillation .	2'·27	3'·02	2'·40	1'·52	0'·16	0'·00	0'·85	1'·96	3'·12	3'·95
Diurnal declination .	36' 54" +1°	37' 39"	37' 02"	36' 09"	34' 48"	34' 38"	35' 29"	36' 36"	37' 45"	38' 35'
$\alpha\left(1+\frac{H}{F}\right)=40''{\cdot}7\times1{\cdot}000451$. Declinometer No. V.										
Sums	660·0	655·0	647·4	626·0	617·2	608·3	635·2	661·1	685·8	708·
Means of 16 days ...	41·25	40·94	40·46	39·13	38·58	38·02	39·70	41·32	42·86	44·3
Diurnal changes ...	−0'·74	−0'·95	−1'·28	−2'·18	−2'·56	−2'·94	−1'·80	−0'·70	+0'·35	+1'·3
Diurnal oscillation .	2'·20	1'·99	1'·66	0'·76	0'·38	0'·00	1'·14	2'·24	3'·29	4'·2
Diurnal declination .	36' 33" +1°	36' 20"	36' 00"	35' 06"	34' 43"	34' 21"	35' 29"	36' 35"	37' 38"	38' 37

ABLE A

of November, 1848. Latitude 1° 18′ 32″ N. Longitude 103° 56′ 30″ E. (*Continued.*)

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
Zero from the 13th to the 30th, 48·11. α=1° 35′ 29″ East.											
845·9	841·4	843·1	831·9	822·0	821·4	818·1	813·9	808·2	15305·4	805·7	
52·87	52·59	52·69	51·99	51·38	51·34	51·13	50·87	50·51	956·59	50·35	1° 37′ 43″
+2′·52	+2′·24	+2′·34	+1′·64	+1′·03	+0′·99	+0′·78	+0′·52	+0′·16			
5′·68	5′·40	5′·50	4′·80	4′·19	4′·15	3′·94	3′·68	3′·32			
40′ 15″	39′ 58″	40′ 04″	39′ 22″	38′ 45″	38′ 43″	38′ 30″	38′ 15″	37′ 53″			
Zero from the 13th to the 30th, 96·33. α=1° 35′ 29″ East.											
1610·8	1606·9	1607·6	1596·7	1587·1	1585·2	1582·9	1577·2	1571·9	29866·9	1572·0	
100·68	100·43	100·48	99·79	99·19	99·08	98·93	98·58	98·24	1866·71	98·25	1° 37′ 23″
+2′·43	+2′·18	+2′·23	+1′·54	+0′·94	+0′·83	+0′·68	+0′·33	−0′·01			
5′·29	5′·04	5′·09	4′·40	3′·80	3′·69	3′·54	3′·19	2′·85			
39′ 50″	39′ 35″	39′ 38″	38′ 57″	38′ 21″	38′ 14″	38′ 05″	37′ 44″	37′ 24″			
Zero from the 13th to the 30th, 95·98. α=1° 35′ 29″ East.											
1502·6	1600·0	1603·2	1592·6	1585·4	1585·4	1576·4	1570·6	1563·3	28844·3	1569·7	
100·17	100·00	100·20	99·54	99·09	99·09	98·53	98·21	97·71	1863·61	98·11	1° 37′ 37″
+2′·06	+1′·89	+2′·09	+1′·43	+0′·98	+0′·98	+0′·42	+0′·10	−0′·40			
5′·04	4′·87	5′·07	4′·41	3′·96	3′·96	3′·40	3′·00	2′·58			
39′ 40″	39′ 30″	39′ 42″	39′ 03″	38′ 36″	38′ 36″	38′ 02″	37′ 38″	37′ 13″			
Zero from the 13th to the 30th, 39·70. α=1° 35′ 29″ East.											
733·3	725·6	724·9	716·2	699·6	699·7	695·8	688·5	682·2	12870·6	677·3	
45·83	45·35	45·31	44·76	43·73	43·73	43·49	43·03	42·64	804·43	42·34	1° 37′ 17″
+2′·37	+2′·05	+2′·02	+1′·65	+0′·94	+0′·95	+0′·78	+0′·47	+0′·20			
5′·31	4′·99	4′·96	4′·59	3′·88	3′·89	3′·72	3′·41	3′·14			
39′ 39″	39′ 20″	39′ 18″	38′ 56″	38′ 13″	38′ 14″	38′ 04″	37′ 45″	37′ 29″			

TABLE A

Observatory at Singapore.—Hourly observations made during the

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000305=1'\cdot000305.$ Declinometer No. I.										
Sums	203·3	199·5	195·0	181·9	170·0	172·9	187·9	201·7	213·6	228·6
Means of 14 days ...	14·52	14·25	13·93	12·99	12·14	12·35	13·42	14·41	15·26	16·33
Diurnal changes ...	−0′·30	−0′·57	−0′·89	−1′·83	−2′·68	−2′·47	−1′·40	−0′·41	+0′·44	+1′·51
Diurnal oscillation...	2·38	2′·11	1′·79	0′·85	0′·00	0′·21	1′·28	2′·27	3′·12	4′·19
Diurnal declination .	36′ 35″ +1°	36′ 20″	36′ 00″	35′ 03″	34′ 12″	34′ 25″	35′ 29″	36′ 28″	37′ 19″	38′ 24
$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000371=1'\cdot000371.$ Declinometer No. II										
Sums	706·0	703·0	699·4	686·0	667·9	668·5	685·9	702·9	717·7	731·3
Means of 14 days ...	50·43	50·21	49·96	49·00	47·71	47·75	48·99	50·21	51·26	52·24
Diurnal changes ...	−0′·31	−0′·53	−0′·78	−1′·74	−3′·03	−2′·99	−1′·75	−0′·53	+0′·52	+1′·50
Diurnal oscillation...	2′·72	2′·50	2′·25	1′·29	0′·00	0′·04	1′·28	2′·50	3′·55	4′·53
Diurnal declination .	36′ 55″ +1°	36′ 42″	36′ 27″	35′ 30″	34′ 12″	34′ 15″	35′ 29″	36′ 42″	37′ 45″	38′ 44
$\alpha\left(1+\frac{H}{F}\right)=1'\cdot0047\times 1\cdot00037=1'\cdot004.$ Declinometer No. III.										
Sums	1375·0	1371·5	1366·4	1353·7	1340·6	1344·2	1358·9	1373·7	1385·9	1401·0
Means of 14 days ...	98·21	97·96	97·60	96·69	95·76	96·01	97·06	98·12	98·99	100·07
Diurnal changes......	−0′·32	−0′·57	−0′·93	−1′·84	−2′·77	−2′·52	−1′·47	−0′·41	+0′·46	+1′·54
Diurnal oscillation...	2′·45	2′·20	1′·84	0′·93	0′·00	0′·25	1′·30	2′·36	3′·23	4′·31
Diurnal declination .	36′ 38″ +1°	36′ 23″	36′ 01″	35′ 09″	34′ 11″	34′ 26″	35′ 29″	36′ 33″	37′ 25″	38′ 30″
$\alpha\left(1+\frac{H}{F}\right)=1'\ 0005\times 1\cdot0003=1'\cdot0008.$ Declinometer No. IV.										
Sums	1345·2	1341·9	1337·5	1325·9	1308·3	1306·9	1320·3	1335·2	1347·9	1363·4
Means of 14 days ...	96·09	95 85	95·54	94·71	93·45	93·35	94·31	95·37	96·28	97·39
Diurnal changes ...	−0′·06	−0′·30	−0′·61	−1′·44	−2′·70	−2′·80	−1′·84	−0′·78	+0′·13	+1′·24
Diurnal oscillation...	2′·74	2′·50	2′·19	1′·36	0′·10	0′·00	0′·96	2′·02	2′·93	4′·04
Diurnal declination .	37′ 16″ +1°	37′ 01″	36′ 43″	35′ 53″	34′ 37″	34′ 31″	35′ 29″	36′ 33″	37′ 27″	38′ 34

ABLE A.

Month of December, 1848. Latitude 1° 18′ 32″ N. Longitude 103° 56′ 30″ E.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
Zero from the 1st to the 16th, 13·42. α=1° 35′ 29″ East.											
240·1	238·6	231·8	226·3	216·6	209·8	212·4	208·4	202·9	3941·3	207·6	
17·15	17·04	16·56	16·16	15·47	14·99	15·17	14·89	14·49	281·52	14·82	1° 36′ 53″
2′·33	+2′·22	+1′·74	+1′·34	+0′·65	+0′·17	+0′·35	+0′·07	−0′·33			
5′·01	4′·90	4′·42	4′·02	3′·33	2′·85	3′·03	2′·75	3′·01			
′ 13″	39′ 06″	38′ 37″	38′ 13″	37′ 32″	37′ 03″	37′ 14″	36′ 57″	37′ 13″			
Zero from the 1st to the 16th, 48·99. α=1° 35′ 29″ East.											
743·8	744·9	736·5	731·1	722·0	714·3	715·3	712·5	707·8	13496·8	710·3	
53·13	53·21	52·61	52·22	51·57	51·02	51·09	50·89	50·56	964·06	50·74	1° 37′ 14″
2′·39	+2′·47	+1′·87	+1′·48	+0′·83	+0′·28	+0′·35	+0′·15	−0′·18			
5′·42	5′·50	4′·90	4′·51	3′·86	3′·31	3′·38	3′·18	2′·85			
′ 37″	39′ 42″	39′ 06″	38′ 43″	38′ 04″	37′ 31″	37′ 35″	37′ 23″	37′ 03″			
Zero from the 1st to the 16th, 97·06. α=1° 35′ 29″ East.											
412·1	1411·2	1404·1	1398·6	1389·2	1382·2	1384·8	1380·3	1374·8	26208·2	1379·2	
00·86	100·80	100·29	99·90	99·23	98·73	98·91	98·59	98·20	1871·98	98·53	1° 36′ 57″
2′·33	+2′·27	+1′·76	+1′·37	+0′·70	+0′·20	+0′·38	+0′·06	−0′·33			
5′·10	5′·04	4′·53	4′·14	3′·47	2′·97	3′·15	2′·83	2′·44			
9′ 17″	39′ 13″	38′ 43″	38′ 19″	37′ 39″	37′ 09″	37′ 20″	37′ 01″	36′ 37″			
Zero from the 1st to the 16th, 94·31. α=1° 35′ 29″ East.											
375·6	1375·8	1368·1	1364·1	1357·2	1351·6	1353·9	1351·6	1345·2	25575·6	1345·9	
98·26	98·27	97·72	97·44	96·94	96·54	96·71	96·54	96·09	1826·85	96·15	1° 37′ 19″
2′·11	+2′·12	+1′·57	+1′·29	+0′·79	+0′·39	+0′·56	+0′·39	−0′·06			
4′·90	4′·92	4′·37	4′·09	3′·59	3′·19	3′·36	3′·19	3′·74			
9′ 25″	39′ 27″	38′ 54″	38′ 37″	38′ 07″	37′ 43″	37′ 53″	37′ 43″	37′ 16″			

Table A

Observatory at Singapore.—Hourly observations made during the Month

$\alpha\left(1+\frac{H}{F}\right)=40''\cdot7\times1\cdot000451.$ Declinometer No. V.

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	592·5	588·0	583·0	562·4	546·0	554·7	570·8	589·5	607·0	626·
Means of 14 days ...	42·32	42·00	41·64	40·17	39·00	39·62	40·77	42·11	43·36	44·7
Diurnal changes ...	−0′·37	−0′·58	−0′·83	−1′·83	−2′·63	−2′·20	−1′·42	−0′·51	+0′·34	+1′·2
Diurnal oscillation...	2′·26	2′·05	1′·80	0′·80	0′·00	0′·43	1′·21	2′·12	2′·97	3′·9
Diurnal declination .	36′ 32″ +1°	36′ 19″	36′ 04″	35′ 04″	34′ 16″	34′ 42″	35′ 29″	36′ 24″	37′ 15″	38′ 12

Observatory at Pulo Booaya.—Hourly observations made during th

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000158=1'\cdot000158.$ Declinometer No. I

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	......	......	126·1	161·9	160·9	162·8	165·6	169·5	173·6	175
Means of 4 days ...	......	......	42·03	40·48	40·23	40·70	41·40	42·38	43·40	43·9
Diurnal changes ...	......	......	−0′·29	−1′·84	−2′·09	−1′·62	−0′·92	+0′·06	+1′·08	+1′·6
Diurnal oscillation...	......	......	1′·80	0′·25	0′·00	0′·47	1′·17	2′·15	3′·17	3′·7
Diurnal declination .	......	......	29′ 27″ +1°	27′ 54″	27′ 39″	28′ 07″	28′ 49″	29′ 48″	30′ 49″	31′ 2

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000139=1'\cdot000139.$ Declinometer No. I

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	......	......	151·7	195·8	194·0	194·6	198·8	203·6	207·4	209
Means of 4 days ...	......	......	50·57	48·95	48·50	48·65	49·70	50·90	51·85	52·
Diurnal changes ...	......	......	−0′·22	−1′·84	−2′·29	−2′·14	−1′·09	+0′·11	+1′·06	+1′·
Diurnal oscillation...	......	......	2′·07	0′·45	0′·00	0′·15	1′·20	2′·40	3′·35	3′·
Diurnal declination .	......	......	29′ 41″ +1°	28′ 04″	27′ 37″	27′ 46″	28′ 49″	30′ 01″	30′ 58″	31′ 2

Observatory at Carimon Island.—Hourly observations made during th

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000158=1'\cdot000158.$ Declinometer No

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	......	......	199·1	233·4	229·3	232·0	238·7	244·9	248·2	249
Means of 6 days ...	......	......	39·82	38·90	38·22	38·67	39·78	40·82	41·37	41·
Diurnal changes ...	......	......	−0′·18	−1′·10	−1′·78	−1′·33	−0′·22	+0′·82	+1′·37	+1′
Diurnal oscillation...	......	......	1′·60	0′·68	0′·00	0′·45	1′·56	2′·60	3′·15	3′·
Diurnal declination .	......	......	23′ 07″ +1°	22′ 12″	21′ 31″	21′ 58″	23′ 05″	24′ 07″	24′ 40″	24′ 5

ABLE A.

f December, 1848. Latitude 1° 18′ 32″ N. Longitude 103° 56′ 30″ E. (*Continued.*)

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
ro from the 1st to the 16th, 40·77. α=1° 35′ 29″ East.											
645·2	646·5	636·3	628·8	614·0	604·3	605·6	602·6	597·1	11401·0	600·1	
46·09	46·18	45·45	44·91	43·86	43·16	43·26	43·04	42·65	814·35	42·86	1° 37′ 34″
2′·20	+2′·26	+1′·76	+1′·32	+0′·68	+0′·20	+0′·27	+0′·12	−0′·14			
4′·83	4′·89	4′·39	3′·95	3′·31	2′·83	2′·90	2′·75	2′·49			
9′ 02″	39′ 10″	38′ 40″	38′ 13″	37′ 35″	37′ 06″	37′ 10″	37′ 01″	36′ 46″			

Ionth of February, 1846. Latitude 0° 09′ 09″ N. Longitude 104° 21′ 00″ E.

Zero from the 6th to the 9th, 41·40. α=1° 28′ 49″ East.											
175·0	172·8	170·7	170·5	170·2	170·8	170·2	127·3	……	2623·7	169·3	
43·75	43·20	42·68	42·63	42·55	42·70	42·55	42·43	……	677·06	42·32	29′ 43″
1′·43	+0′·88	+0′·36	+0′·31	+0′·23	+0′·38	+0′·23	+0′·11	……			
3′·52	2′·97	2′·45	2′·40	2′·32	2′·47	2′·32	2′·20	……			
1′ 10″	30′ 37″	30′ 06″	30′ 03″	29′ 58″	30′ 07″	29′ 58″	29′ 51″	……			
Zero from the 6th to the 9th, 49·70. α=1° 28′ 49″ East.											
208·5	207·3	205·4	205·3	205·1	205·2	205·0	152·2	……	3149·0	203·2	
52·13	51·83	51·35	51·33	51·28	51·30	51·25	50·73	……	812·60	50·79	29′ 55″
1′·34	+1′·04	+0′·56	+0′·54	+0′·49	+0′·51	+0′·46	−0′·06	……			
3′·63	3′·33	2′·85	2′·83	2′·78	2′·80	2′·75	2′·23	……			
1′ 15″	30′ 57″	30′ 28″	30′ 27″	30′ 24″	30′ 25″	30′ 22″	29′ 51″	……			

Ionth of January, 1846. Latitude 0° 59′ 22″ N. Longitude 103° 27′ 00″ E.

Zero from the 26th to the 31st of January, 39·78. α=1° 23′ 05″ East.											
48·6	246·1	241·0	237·5	235·9	237·3	238·8	240·1	……	3800·3	240·0	
41·43	41·02	40·17	39·58	39·32	39·55	39·80	40·02	……	640·04	40·00	1° 23′ 17″
1′·43	+1′·02	+0′·17	−0′·42	−0′·68	−0′·45	−0′·20	+0′·02	……			
3′·21	2′·80	1′·95	1′·36	1′·10	1′·33	1′·58	1′·80	……			
4′ 44″	24′ 19″	23′ 28″	22′ 53″	22′ 37″	22′ 51″	23 ′06″	23′ 19″	……			

TABLE A.

Observatory at Carimon Island.—Hourly observations made during the Month

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000139=1'\cdot000139$. Declinometer No. II.										
Sums	......	......	233·1	271·5	268·2	273·7	281·3	289·0	293·6	296·
Means of 6 days......	......	......	46·62	45·25	44·70	45·62	46·88	48·17	48·93	49·3
Diurnal changes......	......	......	−0′·91	−2′·28	−2′·83	−1′·91	−0′·65	+0′·64	+1′·40	+1′·8
Diurnal oscillation...	......	......	1′·92	0′·55	0′·00	0′·92	2′·18	3′·47	4′·23	4′·6
Diurnal declination	......	......	22′ 49″ +1°	21′ 27″	20′ 54″	21′ 49″	23′ 05″	24′ 22″	25′ 08″	25′ 34

Observatory at Padang.—Hourly observations made during the Month

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000207=1'\cdot0002$. Declinometer No. I.										
Sums	953·6	952·6	952·8	872·1	947·6	942·3	940·0	934·2	943·6	959·
Means of 12 days ...	79·46	79·38	79·40	79·28	78·97	78·53	78·33	77·85	78·63	79·9
Diurnal changes......	−0′·12	−0′·20	−0′·18	−0′·30	−0′·61	−1′·05	−1′·25	−1′·73	−0′·95	−0′·3
Diurnal oscillation...	1′·61	1′·53	1′·55	1′·43	1′·12	0′·68	0′·48	0′·00	0′·78	2′·1
Diurnal declination	26′ 03″ +1°	25′ 58″	25′ 59″	25′ 52″	25′ 33″	25′ 07″	24′ 55″	24′ 26″	25′ 13″	26′ 33
$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000158=1'\cdot000158$. Declinometer No. II.										
Sums	585·1	584·3	583·9	537·4	577·3	572·3	569·8	569·5	581·4	603·
Means of 13 days ...	45·01	44·95	44·92	44·78	44·41	44·02	43·83	43·80	44·78	46·3
Diurnal changes ...	−0′·57	−0′·63	−0′·66	−0′·80	−0′·17	−1′·56	−1′·75	−1′·78	−0′·80	+0′·8
Diurnal oscillation...	1′·21	1′·15	1′·12	0′·98	0′·61	0′·22	0′·03	0′·00	0′·98	2′·5
Diurnal declination .	25′ 38″ +1°	25′ 32″	25′ 32″	25′ 26″	25′ 02″	24′ 38″	24′ 26″	24′ 26″	25′ 26″	27′ 02

Observatory at Padang.—Hourly observations made during the Mont

$\alpha\left(1+\frac{H}{F}\right)=1'\times1\cdot000207=1'\cdot0002$. Declinometer No. I										
Sums	2059·9	2060·6	2052·8	2034·2	2012·6	2016·1	2017·3	2030·6	2060·3	2085
Means of 26 days ...	79·23	79·25	78·95	78·24	77·41	77·54	77·59	78·10	79·24	80·
Diurnal changes......	−0′·06	−0′·04	−0′·34	−1′·05	−1′·88	−1′·75	−1′·70	−1′·19	−0′·05	+0′·
Diurnal oscillation...	1′·82	1′·84	1′·54	0′·83	0′·00	0′·13	0′·18	0′·69	1′·83	2′·
Diurnal declination .	25′ 32″ +1°	25′ 32″	25′ 14″	24′ 32″	23′ 44″	23′ 50″	23′ 56″	24′ 26″	25′ 32″	26′ 3

TABLE A.

nuary, 1846. Latitude 0° 59′ 22″ N. Longitude 103° 27′ 00″ E. (*Continued.*)

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
o from the 26th to the 31st, 46·88. $\alpha = 1° 23′ 05″$ East.											
295·8	294·4	290·3	287·7	285·2	285·9	285·5	283·8	......	4515·2	285·1	
49·30	49·07	48·38	47·95	47·53	47·65	47·58	47·30	......	760·30	47·53	1° 23′ 41″
1′·77	+1′·54	+0′·85	+0′·42	0′·00	+0′·12	+0′·05	−0′·23	......			
4′·60	4′·37	3′·68	3′·25	2′·83	2′·95	2′·88	2′·60	......			
5′ 30″	25′ 16″	24′ 35″	24′ 09″	23′ 44″	23′ 51″	23′ 47″	23′ 30″	......			

tober, 1847. Latitude 0° 58′ 58″ S. Longitude 100° 31′ 15″ E.

o from the 17th to the 31st, 77·85. $\alpha = 1° 24′ 26″$ East.											
969·1	971·7	969·0	968·1	963·4	961·6	958·5	955·5	950·1	18065·5	955·1	
80·76	80·98	80·75	80·68	80·28	80·13	79·88	79·63	79·18	1512·07	79·58	1° 26′ 10″
1′·18	+1′·40	+1′·17	+1′·10	+0′·70	+0′·55	+0′·30	+0′·05	−0′·40			
2′·91	3′·13	2′·90	2′·83	2′·43	2′·28	2′·03	1′·78	1′·33			
7′ 21″	27′ 34″	27′ 20″	27′ 16″	26′ 52″	26′ 43″	26′ 28″	26′ 14″	25′ 40″			
ro from the 16th to the 30th, 43·83. $\alpha = 1° 24′ 26″$ East.											
618·8	623·5	618·9	563·0	556·0	601·0	598·0	592·1	585·4	11120·7	592·8	
47·60	47·96	47·60	46·92	46·33	46·23	46·00	45·41	45·03	865·97	45·58	1° 26′ 14″
+2′·02	+2′·38	+2′·02	+1′·34	+0′·75	+0′·65	+0′·42	−0′·17	−0′·55			
3′·80	4′·16	3′·80	3′·12	2′·53	2′·43	2′·20	1′·61	1′·23			
7′ 44″	28′ 38″	28′ 14″	27′ 32″	26′ 56″	26′ 50″	26′ 38″	26′ 02″	25′ 38″			

of November, 1847. Latitude 0° 58′ 58″ S. Longitude 100° 31′ 15″ E.

ro from the 1st to the 31st, 78·10. $\alpha = 1° 24′ 26″$ East.											
2099·6	2102·3	2095·4	2088·9	2079·0	2073·9	2074·1	2066·8	2059·8	39169·5	2061·55	
80·75	80·86	80·59	80·34	79·96	79·77	79·77	79·49	79·22	1506·50	79·29	1° 25′ 38″
+1′·46	+1′·57	+1′·30	+1′·05	+0′·67	+0′·48	+0′·48	0′·20	−0′·07			
3′·34	3′·45	3′·18	2′·93	2′·55	2′·36	2′·36	2′·08	1′·81			
7′ 02″	27′ 14″	26′ 56″	26′ 38″	26′ 14″	26′ 08″	26′ 08″	25′ 50″	25′ 32″			

TABLE A.

Observatory at Padang.—Hourly observations made during the

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$\alpha\left(1+\frac{H}{F}\right)=1'\times\cdot000158=1'\cdot000158$. Declinometer No. II.										
Sums	1154·7	1153·5	1145·9	1127·6	1103·2	1107·3	1110·6	1130·8	1166·8	1199·2
Means of 26 days ...	44·41	44·37	44·07	43·37	42·43	42·59	42·72	43·49	44·88	46·12
Diurnal changes ...	−0'·44	−0'·48	−0'·78	−1'·48	−2'·42	−2'·26	−2'·13	−1'·36	+0'·03	+1'·27
Diurnal oscillation...	1'·98	1'·94	1'·64	0'·94	0'·00	0'·16	0'·29	1'·06	2'·45	3'·69
Diurnal declination .	25' 20'' +1°	25' 20''	25' 02''	24' 20''	23' 20''	23' 32''	23' 38''	24' 26''	25' 50''	27' 02''

Observatory at Padang.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times\cdot000207=1'\cdot002$. Declinometer No. I.										
Sums	2042·3	2039·9	2031·4	2013·5	1986·0	1970·1	1982·1	2000·1	2021·3	2052·6
Means of 26 days ...	78·55	78·46	78·13	77·44	76·38	75·77	76·23	76·93	77·74	78·95
Diurnal changes......	+0'·21	+0'·12	−0'·21	−0'·90	−1'·96	−2'·57	−2'·11	−1'·41	−0'·60	+0'·61
Diurnal oscillation...	2'·78	2'·69	2'·36	1'·67	0'·61	0'·00	0'·46	1'·16	1'·97	3'·18
Diurnal declination .	26' 02'' +1°	25' 56''	25' 38''	24' 56''	23' 56''	23' 20''	24' 38''	24' 26''	25' 14''	26' 26''
$\alpha\left(1+\frac{H}{F}\right)=1'\times\cdot000158=1'\cdot000158$. Declinometer No. II.										
Sums	1165·7	1163·8	1155·2	1139·2	1107·6	1096·5	1115·0	1143·5	1174·7	1214·2
Means of 26 days ...	44·83	44·76	44·43	43·82	42·60	42·17	42·88	43·98	45·18	46·70
Diurnal changes ...	−0'·63	−0'·70	−1'·03	−1'·64	−2'·86	−3'·29	−2'·58	−1'·48	−0'·28	+1'·24
Diurnal oscillation...	2'·66	2'·59	2'·26	1'·65	0'·43	0'·00	0'·71	1'·81	3'·01	4'·53
Diurnal declination .	25' 14'' +1°	25' 14''	24' 50''	24' 14''	23' 02''	22' 38''	23' 20''	24' 26''	25' 38''	27' 08''

Observatory at Padang.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times\cdot000207=1'\cdot002$. Declinometer No. I.										
Sums	1003·5	1001·5	998·7	988·6	976·8	974·6	979·4	984·5	990·9	1006·1
Means of 13 days ...	77·19	77·04	76·82	76·05	75·14	74·97	75·34	75·73	76·22	77·39
Diurnal changes ...	+0'·20	+0'·05	−0'·17	−0'·94	−1'·85	−2'·02	−1'·65	−1'·26	−0'·77	+0'·40
Diurnal oscillation...	2'·22	2'·07	1'·85	1'·08	0'·17	0'·00	0'·37	0'·76	1'·25	2'·42
Diurnal declination .	25' 56'' +1°	25' 44''	25' 32''	24' 44''	25' 02''	25' 08''	24' 50''	24' 26''	24' 56''	26' 08''

TABLE A.

Month of November, 1847. Latitude 0° 58′ 58″ S. Longitude 100° 31′ 15″ E. (*Continued.*)

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
Zero from the 1st to the 30th, 43·49. α=1° 24′ 26″ East.											
1217·7	1223·0	1217·3	1208·1	1194·5	1184·7	1180·6	1169·9	1162·2	22157·6	1166·20	
46·83	47·04	46·82	46·47	45·94	45·57	45·41	44·99	44·70	852·22	44·85	1° 25′ 44″
+1′·98	+2′·19	+1′·97	+1′·62	+1′·09	+0′·72	+0′·56	+0′·14	−0′·15			
4′·40	4′·61	4′·39	4′·04	3′·51	3′·14	2′·98	2′·56	2′·27			
7′ 44″	27′ 56″	27′ 44″	27′ 26″	26′ 50″	26′ 32″	26′ 20″	25′ 56″	25′ 38″			

Month of December, 1847. Latitude 0° 58′ 58″ S. Longitude 100° 31′ 15″ E.

Zero from the 1st to the 31st, 76·93. α=1° 24′ 26″ East.											
2067·6	2072·7	2080·5	2078·2	2066·0	2049·1	2051·9	2050·6	2044·2	38700·1	2036·6	
79·52	79·72	80·02	79·93	79·46	78·81	78·92	78·87	78·62	1488·45	78·34	1° 25′ 50″
+1′·18	+1′·38	+1′·68	+1′·59	+1′·12	+0′·47	+0′·58	+0′·53	+0′·28			
3′·75	3′·95	4′·25	4′·16	3′·69	3′·04	3′·15	3′·10	2′·85			
27′ 02″	27′ 14″	27′ 32″	27′ 26″	27′ 02″	26′ 20″	26′ 26″	26′ 26″	26′ 08″			
Zero from the 1st to the 31st, 43·98. α=1° 24′ 26″ East.											
1237·2	1244·9	1255·0	1246·3	1228·4	1202·3	1197·4	1189·0	1179·8	22455·7	1181·7	
47·58	47·88	48·27	47·93	47·25	46·24	46·05	45·73	45·38	863·66	45·46	1° 25′ 56″
+2′·12	+2′·42	+2′·81	+2′·47	+1′·79	+0′·78	+0′·59	+0′·27	−0′·08			
5′·41	5′·71	6′·10	5′·76	5′·08	4′·07	3′·88	3′·56	3′·21			
27′ 44″	28′ 10″	28′ 44″	28′ 20″	27′ 38″	26′ 38″	26′ 26″	26′ 08″	25′ 50″			

Month of January, 1848. Latitude 0° 58′ 58″ S. Longitude 100° 31′ 15″ E.

Zero from the 1st to the 15th, 75·73. α=1° 24′ 26″ East.											
1013·6	1016·7	1019·4	1018·7	1010·9	1007·4	1015·2	1007·7	1003·5	19017·7	1001·0	
77·97	78·21	78·42	78·36	77·76	77·49	78·09	77·52	77·19	1462·90	76·99	1° 25′ 44″
+0′·98	+1′·22	+1′·43	+1′·37	+0′·77	+0′·50	+1′·10	+0′·53	+0′·20			
3′·00	3′·24	3′·45	3′·39	2′·79	2′·54	3′·12	2′·55	2′·22			
26′ 44″	26′ 56″	27′ 08″	27′ 08″	26′ 32″	26′ 14″	26′ 50″	26′ 14″	25′ 56″			

TABLE A.

Observatory at Padang.—Hourly observations made during the Month of

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000158=1'\cdot000158.$ Declinometer No. II.

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	......	......	......	585·7	583·3	579·4	569·7	558·4	557·7	567·4	576·4	587·3	606·9
Means of 13 days ...	......	......	......	45·05	44·87	44·57	43·82	42·95	42·90	43·65	44·34	45·18	46·68
Diurnal changes ...	......	......	......	−0′·62	−0′·80	−1′·10	−1′·85	−2′·72	−2′·77	−2′·02	−1′·33	−0′·49	+1′·01
Diurnal oscillation...	......	......	......	2′·15	1′·97	1′·67	0′·92	0′·05	0′·00	0′·75	1′·41	2′·28	3′·78
Diurnal declination .	......	......	......	25′ 08″ +1°	25′ 02″	24′ 44″	23′ 56″	23′ 02″	23′ 02″	23′ 44″	24′ 26″	25′ 20″	26′ 50″

Observatory at Poolo Bay.—Hourly observations made during the Months of

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000207=1'\cdot000207.$ Declinometer No. I.

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	......	......	......	458·0	458·5	459·4	462·4	278·4	456·2	449·9	448·0	447·3	449·2
Means of 5 days ...	......	......	......	91·60	91·70	91·88	92·48	92·80	91·24	89·98	89·60	89·46	89·84
Diurnal changes ...	......	......	......	+0′·39	+0′·49	+0′·67	+1′·27	+1′·59	+0′·03	−1′·23	−1′·61	−1′·75	−1′·37
Diurnal oscillation...	......	......	.....	2′·14	2′·24	2′·42	3′·02	3′·34	1′·78	0′·52	0′·14	0′·00	0′·38
Diurnal declination .	......	......	......	06′ 46″ +1°	06′ 52″	07′ 03″	07′ 39″	07′ 58″	06′ 25″	05′ 09″	05′ 32″	05′ 38″	05′ 01″

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000158=1'\cdot000158.$ Declinometer No. II.

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	......	......	......	98·2	98·9	100·1	102·1	100·7	98·6	96·0	94·5	93·9	94·6
Means of 2 days ...	......	......	......	49·10	49·45	50·05	51·05	50·35	49·30	48·00	47·25	46·95	47·30
Diurnal changes......	......	......	......	−0′·55	−0′·20	+0′·40	+1′·40	+0′·70	−0′·35	−1′·65	−2′·40	−2′·70	−2′·35
Diurnal oscillation ...	......	......	......	2′·15	2′·50	3′·10	4′·10	3′·40	2′·35	1′·05	0′·30	0′·00	0′·35
Diurnal declination .	......	......	......	06′ 15″ +1°	06′ 36″	07′ 12″	08′ 12″	07′ 30″	06′ 27″	05′ 09″	04′ 24″	04′ 06″	04′ 27″

Observatory at Batavia.—Hourly observations made during the Month of

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000207=1'\cdot000207.$ Declinometer No. I.

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	1514·8	1592·5	1593·3	1589·8	1589·0	1587·7	1570·5	1559·3	1556·0	1563·8	1576·9	1598·1	1623·6
Means of 19 days ...	84·16	83·82	83·86	83·67	83·63	83·56	82·66	82·07	81·89	82·30	82·99	84·11	85·45
Diurnal changes ...	0′·0	−0′·4	−0′·3	−0′·5	−0′·6	−0′·6	−1′·5	−2′·1	−2′·3	−1′·9	−1′·2	−0′·1	+1′·2
Diurnal oscillation...	2′·3	1′·9	2′·0	1′·8	1′·7	1′·7	0′·8	0′·2	0′·0	0′·4	1′·1	2′·2	3′·3
Diurnal declination .	49′ 01″ +0°	48′ 37″	48′ 43″	48′ 31″	48′ 25″	48′ 25″	47′ 31″	46′ 55″	46′ 43″	47′ 07″	47′ 49″	48′ 55″	50′ 13″

ABLE A.

January, 1848. Latitude 0° 58′ 58″ S. Longitude 100° 31′ 15″ E. (*Continued.*)

1	2.	3.	4.	5.	6.	7.	8.	9.	10.	11·	Sums.	Means.	Declin.
Zero from the 1st to the 15th, 44·34 α=1° 24′ 26″ East.													
618·7	624·5	626·5	622·2	611·2	604·9	608·0	598·8	593·7	......	......	11280·7	593·7	
47·59	48·04	48·19	47·86	47·02	46·53	46·77	46·06	45·67	......	......	867·74	45·67	1° 25′ 50″
+1′·92	+2′·37	+2′·52	+2′·19	+1′·35	+0′·86	+1′·10	+0′·39	0′·00	......	......			
4′·69	5′·14	5′·29	4′·96	4′·12	3′·63	3′·87	3′·16	2′·77	......	......			
27′ 44″	28′ 08″	28′ 20″	28′ 02″	27′ 08″	26′ 38″	26′ 56″	36′ 14″	25′ 50″	......	......			

August and September, 1847. Latitude 3° 53′ 54″ S. Longitude 102° 28′ 45″ E.

Zero from the 31st of August to September the 4th inclusive, 89·98. α=1° 05′ 09″ East.													
453·2	457·6	463·3	464·7	459·3	456·3	455·0	453·9	452·2	......	......	8482·8	456·1	
90·64	91·52	92·66	92·94	91·86	91·26	91·00	90·78	90·44	......	......	1733·68	91·21	1° 06′ 23″
−0′·57	+0′·31	+1′·45	+1′·73	+0′·65	+0′·05	−0′·21	−0′·43	−0′·77	......	......			
1′·18	2′·06	3′·20	3′·48	2′·40	1′·80	1′·54	1′·32	0′·98	......	......			
05′ 35″	06′ 41″	08′ 01″	08′ 07″	07′ 02″	06′ 26″	06′ 10″	05′ 57″	05′ 37″	......	......			
Zero from the 31st of August to September the 4th inclusive, 50·86. α=1° 05′ 09″ East.													
96·8	100·1	102·5	102·4	101·9	102·2	101·8	101·3	100·0	......	......	1886·6	99·3	
48·40	50·05	51·25	51·20	50·95	51·10	50·90	50·65	50·00	......	......	943·3	49·65	1° 06′ 48″
−1′·25	+0′·40	+1′·60	+1′·55	+1′·30	+1′·45	+1′·25	+1′·00	+0′·35	......	......			
1′·45	3′·10	4′·30	4′·25	4′·00	4′·15	3′·95	3′·70	3′·05	......	......			
05′ 33″	07′ 12″	08′ 24″	08′ 21″	08′ 06″	08′ 15″	08′ 03″	07′ 48″	07′ 09″	......	......			

November, 1846. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E.

Zero from the 9th to the 30th, 82·30. α=0° 47′ 07″ East.													
1643·3	1644·2	1638·5	1630·4	1623·9	1612·7	1610·5	1605·5	1603·1	1597·1	1597·3	38321·8	1600·2	
86·49	86·54	86·24	85·81	85·47	84·88	84·76	84·50	84·37	84·06	84·07	2021·36	84·22	0° 49′ 01″
+2′·3	+2′·3	+2′·0	+1′·6	+1′·3	+0′·7	+0′·6	+0′·3	+0′·2	−0′·1	−0′·1			
4′·6	4′·6	4′·3	3′·9	3′·6	3′·0	2′·9	2′·6	2′·5	2′·2	2′·2			
51′ 19″	51′ 19″	51′ 01″	50′ 37″	50′ 19″	49′ 43″	49′ 37″	49′ 19″	49′ 19″	48′ 55″	48′ 55″			

TABLE A.

Observatory at Batavia.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1{\cdot}000139=1'{\cdot}000139.$ Declinometer No. II.

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Sums	939·1	988·0	986·8	982·2	980·4	977·8	963·4	948·2	946·0	953·3	969·7	991·2	967·2
Means of 19 days ...	52·17	52·00	51·94	51·69	51·60	51·46	50·70	49·90	49·79	50·17	51·04	52·17	53·73
Diurnal changes ...	−0′·1	−0′·3	−0′·4	−0′·6	−0′·7	−0′·8	−1′·6	−2′·4	−2′·5	−2′·1	−1′·3	−0′·1	+1′·4
Diurnal oscillation...	2′·4	2′·2	2′·1	1′·9	1′·8	1′·7	0′·9	0′·1	0′·0	0′·4	1′·2	2′·4	3′·9
Diurnal declination .	49′ 07″ +0°	48′ 55″	48′ 49″	48′ 37″	48′ 31″	48′ 25″	47′ 57″	46′ 49″	46′ 43″	47′ 07″	47′ 55″	49′ 07″	50′ 37″

Observatory at Batavia.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1{\cdot}000207=1'{\cdot}000207.$ Declinometer No. I.

Sums	2007·7	2006·2	2004·5	2080·5	2076·6	2067·7	2049·0	2022·0	1553·1	1327·6	1344·1	1357·9	2109·
Means of 25 days ...	80·31	80·25	80·18	80·02	79·87	79·53	78·81	77·77	77·66	78·09	79·06	79·88	81·1
Diurnal changes ...	+0′·1	0′·0	0′·0	−0′·2	−0′·3	−0′·7	−1′·4	−2′·4	−2′·5	−2′·1	−1′·1	−0′·3	+0′·
Diurnal oscillation...	2′·6	2′·5	2′·5	2′·3	2′·2	1′·8	1′·1	0′·1	0′·0	0′·4	1′·4	2′·2	3′·
Diurnal declination .	49′ 19″ +0°	49′ 13″	49′ 13″	49′ 01″	48′ 55″	48′ 31″	47′ 49″	46′ 49″	46′ 43″	47′ 07″	48′ 07″	48′ 55″	50′ 07

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1{\cdot}000139=1'{\cdot}000139.$ Declinometer No. II.

Sums	1311·7	1308·8	1304·4	1351·3	1345·2	1336·4	1316·3	1288·6	937·1	846·0	864·2	880·8	1391·
Means of 25 days ...	52·47	52·35	52·18	51·97	51·74	51·40	50·63	49·56	49·32	49·77	50·84	51·81	53·5
Diurnal changes ...	−0′·1	−0′·3	−0′·4	−0′·6	−0′·9	−1′·2	−2′·0	−3′·0	−3′·3	−2′·8	−1′·8	−0′·8	+0′·
Diurnal oscillation...	3′·2	3′·0	2′·9	2′·7	2′·4	2′·1	1′·3	0′·3	0′·0	0′·5	1′·5	2′·5	4′·
Diurnal declination .	49′ 44″ +0°	49′ 37″	49′ 31″	49′ 19″	49′ 01″	48′ 43″	47′ 55″	46′ 55″	46′ 37″	47′ 07″	48′ 07″	49′ 07″	50′ 49

Observatory at Batavia.—Hourly observations made during th

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1{\cdot}000207=1'{\cdot}000207.$ Declinometer No. I

Sums	1416·3	1417·6	1415·1	1977·6	1974·2	1968·3	1955·2	1921·1	1912·0	1923·0	1935·8	1958·1	1992·
Means of 25 days ...	78·68	78·76	78·62	79·10	78·97	78·73	78·21	76·84	76·48	76·92	77·43	78·32	79·6
Diurnal changes ...	−0′·2	−0′·1	−0′·3	+0′·2	+0′·1	−0′·2	−0′·7	−2′·1	−2′·4	−2′·0	−1′·5	−0′·6	+0′·
Diurnal oscillation...	2′·2	2′·3	2′·1	2′·6	2′·5	2′·2	1′·7	0′·3	0′·0	0′·4	0′·9	1′·8	3′·
Diurnal declination .	48′ 55″ +0°	49′ 01″	48′ 49″	49′ 19″	49′ 13″	48′ 55″	48′ 25″	47′ 01″	46′ 43″	47′ 07″	47′ 37″	48′ 31″	49′ 55

ABLE A.

Ionth of November, 1846. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E. (*Continued.*)

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Declin.
ero from the 9th to the 30th, 50·17. α=0° 47′ 07″ East.													
983·5	989·9	986·6	978·4	915·2	1010·8	1006·4	999·5	996·4	989·5	989·2	23438·7	994·0	
54·64	54·99	54·81	54·36	53·84	53·20	52·97	52·60	52·44	52·08	52·06	1256·35	52·32	0° 49′ 13″
+2′·3	+2′·7	+2′·5	+2′·1	+1′·5	+0′·9	+0′·7	+0′·3	+0′·1	−0′·2	−0′·2			
4′·8	5′·2	5′·0	4′·6	4′·0	3′·4	3′·2	2′·8	2′·6	2′·3	2′·3			
′ 31″	51′ 51″	51′ 43″	51′ 19″	50′ 43″	50′ 07″	49′ 55″	49′ 31″	49′ 19″	49′ 01″	49′ 01″			

Ionth of December, 1846. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E.

ero from the 1st to the 31st, 78·11. α=0° 47′ 07″ East.													
130·4	2136·0	2130·8	2121·7	2106·8	2015·1	2014·9	1529·7	1206·3	1202·7	1200·2	43801·4	2085·99	
81·94	82·15	81·95	81·60	81·03	80·60	80·60	80·51	80·42	80·18	80·01	1923·57	80·22	0° 49′ 19″
+1′·7	+1′·9	+1′·7	+1′·4	+0′·8	+0′·4	+0′·4	+0′·3	+0′·2	0′·0	−0′·2			
4′·2	4′·4	4′·2	3′·9	3′·3	2′·9	2′·9	2′·8	2′·7	2′·5	2′·3			
′ 55″	51′ 07″	50′ 55″	50′ 37″	50′ 01″	49′ 37″	49′ 37″	49′ 31″	49′ 25″	49′ 13″	49′ 01″			
ero from the 1st to the 31st, 49·77. α=0° 47′ 07″ East.													
420·1	1429·9	1428·1	1423·1	1409·5	1341·2	1337·7	1011·0	792·0	787·9	782·1	28645·3	1368·87	
54·62	55·00	54·93	54·73	54·21	53·65	53·51	53·21	52·80	52·53	52·14	1258·90	52·56	0° 49′ 55″
+2′·0	+2′·4	+2′·3	+2′·1	+1′·6	+1′·0	+0′·9	+0′·6	+0′·2	−0′·1	−0′·5			
5′·3	5′·7	5′·6	5′·4	4′·9	4′·3	4′·2	3′·9	3′·5	3′·2	2′·8			
1′ 55″	52′ 19″	52′ 13″	52′ 01″	51′ 31″	50′ 55″	50′ 49″	50′ 31″	50′ 07″	49′ 49″	49′ 25″			

Ionth of January, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E.

ero from the 1st to the 31st, 76·9. α=0° 47′ 07″ East.													
020·7	2025·8	2019·0	2003·4	1990·4	1987·2	1991·2	1587·1	1417·2	1413·7	1412·8	43634·8	1975·2	
80·83	81·03	80·76	80·14	79·62	79·49	79·65	79·36	78·73	78·54	78·49	1893·38	78·90	0° 49′ 07″
+1′·9	+2′·1	+1′·9	+1′·2	+0′·7	+0′·6	+0′·7	+0′·5	−0′·2	−0′·4	−0′·4			
4′·3	4′·5	4′·3	3′·6	3′·1	3′·0	3′·1	2′·9	2′·2	2′·0	2′·0			
1′ 01″	51′ 13″	51′ 01″	50′ 19″	49′ 49″	49′ 43″	49′ 49″	49′ 37″	48′ 55″	48′ 43″	48′ 43″			

TABLE A.

Observatory at Batavia.—Hourly observations made during the

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.

$\alpha\left(1+\frac{H}{F}\right)=1'\times\cdot000139=1'\cdot000139.$ Declinometer No. II.

Sums	919·8	919·5	917·6	1258·2	1252·7	1244·0	1229·5	1195·8	1186·0	1198·6	1214·7	1235·6	1283·9
Means of 25 days ...	51·10	51·08	50·98	50·33	50·11	49·76	49·18	47·83	47·44	47·94	48·59	49·42	51·36
Diurnal changes ...	+0′·5	+0′·5	+0′·4	−0′·3	−0′·5	−0′·8	−1′·4	−2′·8	−3′·2	−2′·7	−2′·0	−1′·2	+0′·8
Diurnal oscillation...	3′·7	3′·7	3′·6	2′·9	2′·7	2′·4	1′·8	0′·4	0′·0	0′·5	1′·2	2′·0	4′·0
Diurnal declination .	50′ 19″ +0°	50′ 19″	50′ 13″	49′ 31″	49′ 13″	49′ 01″	48′ 25″	47′ 01″	46′ 37″	47′ 07″	47′ 49″	48′ 37″	50′ 37″

Observatory at Batavia.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000207=1'\cdot000207.$ Declinometer No. I.

Sums	1303·5	1304·9	1304·8	1971·4	1972·8	1973·8	1971·0	1940·3	1907·2	1892·2	1898·2	1928·2	1971·4
Means of 24 days ...	81·47	81·56	81·55	82·14	82·20	82·24	82·13	80·85	79·47	78·84	79·09	80·34	82·14
Diurnal changes ...	−0′·6	−0′·5	−0′·6	0′·0	+0′·1	+0′·1	0′·0	−1′·3	−2′·6	−3′·3	−3′·0	−1′·8	0′·0
Diurnal oscillation .	2′·7	2′·8	2′·7	3′·3	3′·4	3′·4	3′·3	2′·0	0′·7	0′·0	0′·3	1′·5	3′·3
Diurnal declination .	49′ 49″ +0°	49′ 55″	49′ 49″	50′ 25″	50′ 31″	50′ 31″	50′ 25″	49′ 07″	47′ 49″	47′ 07″	47′ 25″	48′ 37″	50′ 25″

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000139=1'\cdot000139.$ Declinometer No. II.

Sums	791·4	795·2	790·0	1183·4	1184·7	1184·1	1178·2	1148·4	1109·5	1095·7	1105·9	1143·9	1193·5
Means of 24 days ...	49·46	49·70	49·38	49·31	49·36	49·34	49·09	47·85	46·23	45·65	46·08	47·66	49·73
Diurnal changes......	−0′·1	+0′·1	−0′·2	−0′·3	−0′·2	−0′·3	−0′·5	−1′·8	−3′·4	−4′·0	−3′·5	−1′·9	+0′·1
Diurnal oscillation...	3′·9	4′·1	3′·8	3′·7	3′·8	3′·7	3′·5	2′·2	0′·6	0′·0	0′·5	2′·1	4′·1
Diurnal declination .	51′ 01″ +0°	51′ 13″	50′ 55″	50′ 49″	50′ 55″	50′ 49″	50′ 37″	49′ 19″	47′ 43″	47′ 07″	47′ 37″	49′ 13″	51′ 13″

Observatory at Batavia.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000207.$ Declinometer No. I.

Sums	......	......	......	2244·0	2237·9	2232·2	2230·5	2213·1	2195·7	2197·8	2214·4	2232·0	2251·5
Means of 27 days ...	......	......	......	83·11	82·89	82·67	82·61	81·97	81·32	81·40	82·02	82·67	83·39
Diurnal changes......	......	......	......	+0′·1	−0′·1	−0′·3	−0′·4	−1′·0	−1′·7	−1′·6	−1′·0	−0′·3	+0′·4
Diurnal oscillation...	......	......	......	1′·8	1′·6	1′·4	1′·3	0′·7	0′·0	1′·1	0′·7	1′·4	2′·1
Diurnal declination .	......	......	......	48′ 49″ +0°	48′ 37″	48′ 25″	48′ 19″	47′ 43″	47′ 01″	47′ 07″	47′ 43″	48′ 25″	49′ 07″

TABLE A.

Month of January, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E. (*Continued.*)

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Declin.
Zero from the 1st to the 31st, 47·94. α=0° 47′ 07″ East.													
1313·1	1323·3	1321·4	1307·1	1295·0	1290·1	1291·3	1037·5	928·6	920·9	918·9	28003·1	1263·0	
52·52	52·93	52·86	52·28	51·80	51·60	51·65	51·88	51·59	51·16	51·05	12164·4	50·64	0° 49′ 49″
+1′·9	+2′·3	+2′·3	+1′·7	+1′·2	+1′·0	+1′·0	+1′·3	+1′·0	+0′·6	+0′·4			
5′·1	5′·5	5′·5	4′·9	4′·4	4′·2	4′·2	4′·5	4′·2	3′·8	3′·6			
51′ 31″	52′ 07″	52′ 07″	51′ 31″	51′ 01″	50′ 49″	50′ 49″	51′ 07″	50′ 49″	49′ 49″	49′ 37″			

Month of February, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E.

Zero from the 1st to the 28th, 78·8. α=0° 47′ 07″ East.													
2010·0	2033·9	2035·7	2023·7	2002·5	1991·1	1990·5	1985·2	1897·2	1138·4	1139·6	43587·5	1972·5	
83·75	84·75	84·82	84·32	83·44	82·96	82·94	82·72	82·49	81·31	81·40	1968·92	82·08	0° 50′ 25″
+1′·6	+2′·6	+2′·7	+2′·2	+1′·3	+0′·9	+0′·8	+0′·6	+0′·4	−0′·8	−0′·7			
4′·9	5′·9	6′·0	5′·5	4′·6	4′·2	4′·1	3′·9	3′·7	2′·5	2′·6			
52′ 01″	53′ 01″	53′ 07″	52′ 37″	51′ 31″	51′ 19″	51′ 13″	51′ 01″	50′ 49″	49′ 37″	49′ 43″			
Zero from the 1st to the 28th, 45·65. α=0° 47′ 07″ East.													
1235·0	1262·4	1266·6	1256·0	1234·1	1223·6	1219·6	1213·4	1156·7	696·9	697·8	26366·0	1192·0	
51·46	52·60	52·78	52·33	51·42	50·98	50·82	50·56	50·30	49·78	49·84	1191·71	49·65	0° 51′ 07″
+1′·9	+3′·0	+3′·2	+2′·7	+1′·8	+1′·4	+1′·2	+1′·0	+0′·7	+0′·2	+0′·2			
5′·9	7′·0	7′·2	6′·7	5′·8	5′·4	5′·2	5′·0	4′·7	4′·2	4′·2			
53′ 01″	54′ 57″	54′ 19″	53′ 49″	52′ 55″	52′ 31″	52′ 19″	52′ 07″	51′ 49″	51′ 19″	51′ 19″			

Month of March, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E.

Zero from the 1st to the 31st, 81·4. α=0° 47′ 07″ East.													
2263·7	2270·8	2267·7	2264·4	2258·6	2254·0	2252·8	2246·7	2148·3	......	......	42476·1	2240·1	
83·84	84·10	83·99	83·87	83·65	83·48	83·44	83·21	82·63	......	......	1576·26	82·96	0° 48′ 43″
+0′·8	+1′·1	+1′·0	+0′·9	+0′·6	+0′·5	+0′·4	+0′·2	−0′·4	......	......			
2′·5	2′·8	2′·7	2′·6	2′·3	2′·2	2′·1	1′·9	1′·3	......	......			
49′ 31″	49′ 49″	47′ 43″	49′ 37″	49′ 19″	49′ 13″	49′ 07″	48′ 55″	48′ 19″	......	......			

TABLE A.

Observatory at Batavia.—Hourly observations made during the

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000139=1'\cdot000139$. Declinometer No. II.										
Sums	1361·5	1354·4	1343·8	1339·0	1322·7	1299·9	1305·5	1321·2	1347·3	1370·4
Means of 27 days ...	50·43	50·16	49·77	49·59	48·99	48·14	48·35	48·93	49·90	50·76
Diurnal changes ...	0′·0	−0′·2	−0′·6	−0′·8	−1′·4	−2′·3	−2′·1	−1′·5	−0′·5	+0′·4
Diurnal oscillation...	2′·3	2′·1	1′·7	1′·5	0′·9	0′·0	0′·2	0′·8	1′·8	2′·7
Diurnal declination .	49′ 13″ +0°	49′ 01″	48′ 37″	48′ 25″	47′ 49″	46′ 55″	47′ 07″	47′ 43″	48′ 43″	49′ 57″

Observatory at Batavia.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000158=1'\cdot000158$. Declinometer No. I.										
Sums	2157·6	2155·3	2150·7	2152·2	2138·6	2112·0	2006·4	2098·4	2118·0	2139·6
Means of 26 days ...	82·98	82·90	82·72	82·78	82·25	81·23	80·26	80·71	81·46	82·29
Diurnal changes......	+0′·5	+0′·4	+0′·2	+0′·3	−0′·3	−1′·3	−2′·2	−1′·8	−1′·0	−0′·2
Diurnal oscillation...	2′·7	2′·6	2′·4	2′·5	1′·9	0′·9	0′·0	0′·4	1′·2	2′·0
Diurnal declination .	49′ 49″ +0°	49′ 43″	49′ 31″	49′ 37″	49′ 01″	48′ 01″	47′ 07″	47′ 31″	48′ 19″	49′ 07″
$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000139=1'\cdot000139$. Declinometer No. II.										
Sums	1305·6	1302·3	1296·5	1295·8	1283·9	1254·3	1184·3	1244·8	1265·2	1293·1
Means of 26 days ...	50·22	50·09	49·87	49·84	49·38	48·24	47·37	47·88	48·66	49·73
Diurnal changes ...	+0′·3	+0′·2	0′·0	−0′·1	−0′·5	−1′·7	−2′·5	−2′·0	−1′·2	−0′·2
Diurnal oscillation...	2′·8	2′·7	2′·5	2′·4	2′·0	0′·8	0′·0	0′·5	1′·3	2′·3
Diurnal declination .	49′ 55″ +0°	49′ 49″	49′ 37″	49′ 31″	49′ 07″	47′ 55″	47′ 07″	47′ 37″	48′ 25″	49′ 25″

Observatory at Batavia.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000158=1'\cdot000158$. Declinometer No. I.										
Sums	2189·2	2190·6	2192·6	2202·7	2203·6	2178·1	1826·7	2147·6	2148·3	2149·9
Means of 26 days ...	84·20	84·25	84·33	84·72	84·75	83·77	83·03	82·60	82·63	82·69
Diurnal changes ...	+0′·3	+0′·3	+0′·4	+0′·8	+0′·8	−0′·1	−0′·9	−1′·3	−1′·3	−1′·2
Diurnal oscillation...	1′·6	1′·6	1′·7	2′·1	2′·1	1′·2	0′·4	0′·0	0′·0	0′·1
Diurnal declination .	43′ 19″ +0°	48′ 19″	48′ 25″	48′ 49″	48′ 49″	47′ 55″	47′ 07″	46′ 43″	46′ 43″	46′ 49″

TABLE A

Month of March, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E. (*Continued.*)

Zero from the 1st to the 31st, 48·35. α=0° 47′ 07″ East.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
1388·7	1397·9	1397·5	1397·8	1394·8	1389·6	1387·1	1379·3	1307·8	25806·2	1360·8	
51·43	51·77	51·76	51·77	51·66	51·47	51·37	51·09	50·30	957·64	50·40	0° 49′ 13″
+1′·0	+1′·4	+1′·4	+1′·4	+1′·3	+1′·1	+1′·0	+0′·7	−0′·1			
3′·3	3′·7	3′·7	3′·7	3′·6	3′·4	3′·3	3′·0	2′·2			
50′ 13″	50′ 37″	50′ 37″	50′ 37″	50′ 31″	50′ 19″	50′ 13″	49′ 55″	49′ 07″			

Month of April, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E.

Zero from the 1st to the 30th, 80·26. α=0° 47′ 07″ East.

2155·4	2166·5	2090·6	2169·4	2165·1	1664·1	1658·6	1651·3	1647·3	38597·1	2144·3	
82·90	83·33	83·62	83·44	83·27	83·21	82·93	82·57	82·37	1567·22	82·47	0° 49′ 19″
+0′·4	+0′·8	+1′·1	+0′·9	+0′·8	+0′·7	+0′·4	+0′·1	−0′·1			
2′·6	3′·0	3′·3	3′·1	3′·0	2′·9	2′·6	2′·3	2′·1			
49′ 31″	50′ 07″	50′ 25″	50′ 13″	50′ 07″	50′ 01″	49′ 43″	49′ 25″	49′ 13″			

Zero from the 1st to the 30th, 47·37. α=0° 47′ 07″ East.

1314·3	1329·5	1287·6	1335·4	1332·8	1024·3	1017·0	1009·4	1002·5	23378·6	1298·8	
50·55	51·13	51·50	51·36	51·26	51·22	50·85	50·47	50·13	949·75	49·95	0° 49′ 37″
+0′·6	+1′·2	+1′·6	+1′·5	+1′·4	+1′·3	+0′·9	+0′·6	+0′·2			
3′·1	3′·7	4′·1	4′·0	3′·9	3′·8	3′·4	3′·1	2′·7			
50′ 13″	50′ 49″	51′ 13″	51′ 07″	51′ 01″	50′ 55″	50′ 31″	50′ 13″	49′ 49″			

Month of May, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E.

Zero from the 1st to the 31st, 83·03. α=0° 47′ 07″ East.

2167·2	2188·0	1865·2	2214·4	2208·4	2107·3	2013·7	2003·0	1996·6	40193·1	2181·7	
83·35	84·15	84·78	85·17	84·94	84·29	83·90	83·46	83·19	1594·20	83·91	0° 48′ 01″
−0′·6	+0′·2	+0′·9	+1′·3	+1′·0	+0′·4	0′·0	−0′·4	−0′·7			
0′·7	1′·5	2′·2	2′·6	2′·3	1′·7	1′·3	0′·9	0′·6			
47′ 25″	48′ 13″	48′ 55″	49′ 19″	49′ 01″	48′ 25″	48′ 01″	47′ 37″	47′ 19″			

Table A.

Observatory at Batavia.—Hourly observations made during the

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000139=1'\cdot000139.$ Declinometer No. II.

Sums	1318·8	1319·5	1319·3	1327·7	1326·9	1305·1	1089·0	1277·9	1280·0	1289·4
Means of 26 days ...	50·72	50·75	50·74	51·07	51·03	50·20	49·50	49·15	49·23	49·59
Diurnal changes ...	0'·0	0'·0	0'·0	+0'·4	+0'·3	−0'·5	−1'·2	−1'·6	−1'·5	−1'·1
Diurnal oscillation...	1'·6	1'·6	1'·6	2'·0	1'·9	1'·1	0'·4	0'·0	0'·1	0'·5
Diurnal declination .	48' 19" +0°	48' 19"	48' 19"	48' 43"	48' 37"	47' 49"	47' 07"	46' 43"	46' 49"	47' 13"

Observatory at Batavia.—Hourly observations made during the

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000158=1'\cdot000158.$ Declinometer No. I.

Sums	2164·8	2167·1	2169·6	2094·5	2110·8	2093·2	1742·3	2063·1	2142·8	2145·2
Means of 26 days ...	83·26	83·35	83·45	83·78	84·43	83·73	82·97	82·52	82·42	82·51
Diurnal changes ...	0'·0	+0'·1	+0'·2	+0'·5	+1'·1	+0'·4	−0'·3	−0'·3	−0'·9	−0'·8
Diurnal oscillation...	0'·9	1'·0	1'·1	1'·4	2'·0	1'·3	0'·6	0'·6	0'·0	0'·1
Diurnal declination .	47' 25" +0°	47' 31"	47' 37"	47' 55"	48' 31"	47' 49"	47' 07"	47' 07"	46' 31"	46' 37"

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000139=1'\cdot000139.$ Declinometer No. II.

Sums	1338·9	1342·2	1341·8	1298·3	1311·7	1296·3	1075·0	1273·7	1326·2	1332·4
Means of 26 days ...	51·50	51·62	51·61	51·93	52·47	51·85	51·19	50·95	51·01	51·25
Diurnal changes ...	−0'·6	−0'·5	−0'·5	−0'·2	+0'·4	−0'·3	−0'·9	−1'·2	−1'·1	−0'·9
Diurnal oscillation...	0'·6	0'·7	0'·7	1'·0	1'·6	0'·9	0'·3	0'·0	0'·1	0'·3
Diurnal declination .	47' 25" +0°	47' 31"	47' 31"	47' 49"	48' 25"	47' 43"	47' 07"	46' 49"	46' 55"	47' 01"

Observatory at Cocos Island.—Hourly observations made during the Month of

$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000305=1'\cdot000305.$ Declinometer No. I.

Sums	2366·0	2370·4	2369·5	2380·2	2368·1	2324·8	2287·9	2277·4	2287·6	2316·2
Means of 27 days ...	87·63	87·79	87·76	88·16	87·71	86·10	84·74	84·35	84·73	85·79
Diurnal changes ...	+0'·53	+0'·69	+0'·66	+1'·06	+0'·61	−1'·00	−2'·36	−2'·75	−2'·37	−1'·21
Diurnal oscillation...	3'·28	3'·44	3'·41	3'·81	3'·36	1'·75	0'·39	0'·00	0'·38	1'·44
Diurnal declination .	07' 49" −1°	07' 39"	07' 41"	07' 17"	07' 44"	09' 20"	10' 42"	11' 05"	10' 43"	9' 39"

TABLE A.

Month of May, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E. (*Continued.*)

Zero from the 1st to the 31st, 49·5. α=0° 47′ 07″ East.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
1311·8	1332·5	1147·4	1365·6	1357·8	1287·5	1225·7	1213·6	1205·6	24301·1	1318·6	
50·45	51·25	52·15	52·52	52·22	51·50	51·07	50·57	50·23	963·94	50·73	0° 48′ 19″
−0′·3	+0′·5	+1′·4	+1′·8	+1′·5	+0′·8	+0′·4	−0′·1	−0′·5			
1′·3	2′·1	3′·0	3′·4	3′·1	2′·4	2′·0	1′·5	1′·1			
48′ 02″	48′ 49″	49′ 43″	50′ 07″	49′ 49″	49′ 07″	48′ 43″	48′ 13″	47′ 49″			

Month of June, 1847. Latitude 6° 09′ 52″ S. Longitude 106° 58′ 00″ E.

Zero from the 1st to the 30th, 32·97. α=0° 47′ 07″ East.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
2152·3	2081·7	1765·2	2104·0	2009·6	1912·3	1741·3	1736·9	1731·3	38128·0	2165·6	
82·78	83·27	84·06	84·16	83·73	83·14	82·92	82·71	82·44	1581·63	83·25	
−0′·5	0′·0	+0′·8	+0′·9	+0′·4	−0′·2	−0′·4	−0′·6	−0′·9			
0′·4	0′·9	1′·7	1′·8	1′·3	0′·7	0′·5	0′·3	0′·0			
46′ 55″	47′ 25″	48′ 13″	48′ 19″	47′ 49″	47′ 13″	47′ 01″	46′ 49″	46′ 31″			

Zero from the 1st to the 30th, 51·19. α=0° 47′ 07″ East.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
1347·0	1315·9	1124·6	1344·8	1281·7	1210·6	1101·6	1094·6	1088·3	23845·6	1352·8	
51·81	52·64	53·55	53·79	53·40	52·63	52·46	52·12	51·82	989·60	52·06	0° 48′ 01″
−0′·3	+0′·5	+1′·4	+1′·7	+1′·3	+0′·5	+0′·4	0′·0	−0′·3			
0′·9	1′·7	2′·6	2′·9	2′·5	1′·7	1′·6	1′·2	0′·9			
47′ 43″	48′ 31″	49′ 25″	49′ 43″	49′ 19″	48′ 31″	48′ 25″	48′ 01″	47′ 43″			

August and September, 1848. Latitude 12° 05′ 38″ S. Longitude 96° 50′ 30″ E.

Zero from August the 28th to September the 27th, 84·74. α=1° 10′ 42″ West.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
2350·1	2377·8	2392·4	2394·2	2379·4	2364·3	2366·6	2358·3	2352·2	45726·8	2351·6	
87·04	88·07	88·61	88·67	88·13	87·57	87·65	87·34	87·12	1654·96	87·10	1° 08′ 28″
−0′·06	+0′·97	+1′·51	+1′·57	+1′·03	+0′·47	+0′·55	+0′·24	+0′·22			
2′·69	3′·72	4′·26	4′·82	3′·78	3′·22	3′·30	2′·99	2′·97			
08′ 24″	07′ 22″	06′ 50″	06′ 46″	07′ 19″	07′ 52″	07′ 47″	08′ 06″	08′ 07″			

TABLE A.

Observatory at Cocos Island.—Hourly observations made during the Month of August

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$\alpha\left(1+\frac{H}{F}\right)=1'\times 1\cdot000371=1'\cdot000371$. Declinometer No. II.										
Sums	1243·8	1247·0	1244·7	1255·6	1242·0	1200·2	1127·5	1175·1	1194·9	1229·5
Means of 27 days	46·07	46·19	46·10	46·50	46·00	44·45	43·37	43·52	44·26	45·54
Diurnal changes	0′·00	+0′·12	+0′·03	+0′·43	−0′·07	−1′·62	−2′·70	−2′·55	−1′·81	−0′·53
Diurnal oscillation	2′·70	2′·82	2′·73	3′·13	2′·63	1′·08	0′·00	0′·15	0′·89	2′·17
Diurnal declination	08′ 00″ −1°	07′ 53″	07′ 58″	07′ 34″	08′ 04″	09′ 37″	10′ 42″	10′ 33″	09′ 49″	08′ 32″
$\alpha\left(1+\frac{H}{F}\right)$ 1′·0047 × 1·00037 = 1′·004. Declinometer No. III.										
Sums	2652·1	2654·5	2755·9	2766·3	2753·7	2610·4	2679·2	2675·7	2695·3	2731·2
Means of 27 days	102·00	102·10	102·07	102·46	101·99	100·40	99·23	99·10	99·83	101·16
Diurnal changes	+0′·01	+0′·11	+0′·08	+0′·47	0′·00	−1′·59	−2′·76	−2′·89	−2′·16	−0′·83
Diurnal oscillation	2′·90	3′·00	2′·97	3′·36	2′·89	1′·30	0′·13	0′·00	0′·73	2′·06
Diurnal declination	07′ 56″ −1°	07′ 50″	7′ 52″	7′ 28″	7′ 56″	9′ 32″	10′ 42″	10′ 50″	9′ 12″	8′ 46″

Table A.

and September, 1848. Latitude 12° 05′ 38″ S. Longitude 96° 50′ 30″ E. (*Continued.*)

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Declin.
Zero from August the 28th to September the 27th, 43·37. α=1° 10′ 42″ West.											
1214·3	1288·0	1298·3	1293·8	1276·5	1254·8	1198·2	1241·2	1232·8	24048·3	1242·6	
46·70	47·70	48·09	47·92	47·28	46·47	46·08	45·97	45·66	873·87	46·07	1° 08′ 00″
+0′·63	+1′·63	+2′·02	+1′·85	+1′·21	+0′·40	+0′·01	−0′·10	−0′·41			
3′·33	4′·33	4′·72	4′·55	3′·91	3′·10	2′·71	2′·60	2′·29			
07′ 22″	06′ 22″	05′ 59″	06′ 09″	06′ 47″	07′ 36″	07′ 59″	08′ 06″	08′ 25″			
Zero from August the 28th to September the 27th, 99·23. α=1° 10′ 42″ West.											
2769·1	2796·3	2811·1	2811·1	2794·6	2773·3	2772·1	2760·7	2752·5	53240·8	2753·4	
102·56	103·57	104·11	104·11	103·50	102·71	102·67	102·25	101·94	1937·76	101·99	1° 07′ 56″
+0′·57	+1′·58	+2′·12	+2′·12	+1′·51	+0′·72	+0′·68	+0′·26	− 0′·05			
3′·46	4′·47	5′·01	5′·01	4′·40	3′·61	3′·57	3′·15	2′·84			
7′ 22″	6′ 22″	5′ 49″	5′ 49″	6′ 26″	7′ 13″	7′ 16″	7′ 41″	7′ 59″			

Oscillation of the Horizontal Intensity at various Stations in the Eastern

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Moulmein	......	......	......	0·00	0·30	0·03	0·55	1·80	5·89	10·19	17·09
Madras	......	......	......	0·28	0·26	0·37	0·56	2·23	5·28	9·73	12·55
Nicobar	......	......	......	2·50	2·86	3·44	4·12	3·28	6·00	9·90	14·46
Sambooanga	......	......	......	0·02	0·00	0·10	0·68	2·55	4·49	6·57	9·59
Penang	......	......	......	0·38	0·52	0·00	0·66	1·90	6·40	10·62	13·74
Pulo Dinding	......	......	......	0·00	0·20	0·40	0·85	2·55	5·35	8·45	11·35
Sarawak	0·35	0·51	0·70	0·80	0·92	1·10	1·47	2·29	3·67	5·31	6·19
Keemah	......	......	......	0·00	0·12	0·21	0·71	2·12	4·35	6·69	8·64
Pulo Peesang	......	......	......	......	......	3·23	0·20	1·44	3·00	6·02	6·90
Singapore	......	......	......	1·53	1·49	1·33	1·84	2·25	3·63	4·63	5·91
Carimon	......	......	......	......	......	0·46	1·07	2·47	4·25	6·32	6·65
Bowaya	......	......	......	......	......	2·28	3·15	4·81	6·41	8·31	8·48
Padang	......	......	......	1·63	1·56	1·67	2·12	3·11	4·60	6·21	7·56
Bencoolen	......	......	......	1·30	1·30	1·20	1·30	4·67	4·38	6·18	7·66
Batavia, Winter	0·51	0·41	0·55	0·33	0·60	0·58	0·76	1·59	2·51	4·18	5·13
Batavia, Spring	......	......	......	0·00	0·18	0·45	0·93	1·88	3·47	4·68	5·78
Cocos	......	......	......	0·98	1·37	1·60	1·81	3·34	4·51	5·79	6·53
Singapore, No. II	......	......	......	0·81	0·70	0·57	0·93	1·25	3·73	5·60	8·07

Oscillation of the Horizontal Intensity at Batavia,

November ......1846...	0·25	0·07	0·41	0·00	0·14	0·36	0·60	1·56	2·83	4·32	5·16
December	0·88	0·85	0·83	0·67	0·74	0·91	1·08	2·05	3·06	4·18	4·72
January ....1847...	0·45	0·26	0·43	0·55	0·73	0·88	0·97	1·88	2·01	4·59	5·95
February	1·38	1·40	1·43	1·02	0·92	1·11	1·31	1·81	3·06	4·57	5·63
Sums	2·96	2·58	3·10	2·24	2·53	3·26	3·96	7·30	10·96	17·66	21·46
Means	0·74	0·64	0·78	0·56	0·63	0·81	0·99	1·82	2·74	4·41	5·36
Oscillation	0·51	0·41	0·55	0·33	0·60	0·58	0·76	1·59	2·51	4·18	5·13

Oscillation of the Horizontal Intensity at Batavia,

March ....1847...	......	......	......	0·00	0·25	0·34	0·51	1·10	2·88	4·35	5·21
April	......	......	......	0·56	0·54	0·60	1·28	2·57	3·95	4·72	6·88
May	......	......	......	0·75	0·93	1·15	1·48	2·50	4·20	5·48	6·01
June	......	......	......	0·00	0·34	1·03	1·79	2·68	4·17	5·49	6·33
Sums	......	......	......	1·31	2·06	3·12	5·06	8·85	15·20	20·04	24·43
Means	......	......	......	0·33	0·51	0·78	1·26	2·21	3·80	5·01	6·11
Oscillation	......	......	......	0·00	0·18	0·45	0·93	1·88	3·47	4·68	5·78

Oscillation of the Horizontal Intensity at Sarawak

June ....1846...	0·49	0·68	0·78	0·98	0·90	1·03	1·50	2·53	3·84	5·44	6·28
July	0·51	0·84	1·07	1·05	1·12	1·43	1·79	2·58	4·33	5·80	6·89
August	0·55	0·51	0·77	0·88	1·25	1·35	1·64	2·28	3·35	5·21	5·90
Sums	1·55	2·03	2·62	2·91	3·27	3·81	4·93	7·39	11·52	16·45	19·07
Means	0·52	0·68	0·87	0·97	1·09	1·27	1·64	2·46	3·84	5·48	6·36
Oscillation	0·35	0·51	0·70	0·80	0·92	1·10	1·47	2·29	3·67	5·31	6·19

Archipelago.—In Scale Divisions. $k = \cdot 000240$.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
21·29	23·43	20·59	20·84	18·55	15·76	12·37	8·30	6·67	4·55	3·06	......	......	10·06
14·15	14·33	12·49	9·38	7·41	5·64	4·51	2·42	0·97	0·16	0·00	......	......	5·41
16·24	16·98	18·20	13·98	8·32	7·06	5·32	3·36	1·48	0·80	0·00	......	......	7·49
11·27	12·59	12·44	9·57	6·01	3·53	2·27	2·42	1·45	1·42	1·97	......	......	4·68
16·56	12·88	9·70	5·22	3·24	3·84	3·64	3·44	3·10	3·14	3·48	......	......	5·39
12·55	11·75	7·75	4·85	3·05	1·35	1·45	2·15	1·20	0·25	1·50	......	......	4·05
6·38	5·94	4·81	3·77	2·05	1·26	0·69	0·01	0·18	0·05	0·00	0·06	0·20	2·03
9·65	9·79	8·74	7·83	5·79	3·96	2·72	2·05	2·30	2·26	2·49	......	......	4·23
6·06	5·20	3·36	2·04	1·86	2·22	1·12	2·18	2·38	1·48	0·00	......	......	2·99
5·80	4·97	3·83	2·94	2·60	1·71	1·33	0·29	0·00	0·27	0·60	......	......	2·48
6·36	2·96	2·22	0·90	0·22	0·00	0·27	0·33	0·14	0·04	......	......	......	2·17
7·15	4·94	3·33	2·80	2·00	0·00	0·75	0·80	0·43	0·08	......	......	......	3·60
7·83	7·33	5·96	4·16	2·82	1·50	1·19	1·32	0·61	0·00	0·16	......	......	3·23
7·92	7·70	5·70	4·90	3·00	2·36	2·12	1·54	1·14	0·38	0·00	......	......	3·46
5·51	5·01	4·20	3·29	2·20	1·24	0·64	0·24	0·12	0·00	0·00	0·27	0·23	1·66
6·27	5·94	4·86	3·22	1·70	0·86	0·34	0·18	0·06	0·13	0·66	......	......	2·19
7·32	7·63	6·53	4·78	3·29	2·02	1·21	0·73	0·49	0·02	0·00	......	......	3·15
9·33	7·13	5·73	3·85	2·85	2·02	1·34	0·30	0·00	0·02	0·17	......	......	2·87

Java, Eastern Archipelago.

5·21	4·81	3·80	3·21	2·20	1·41	0·72	0·40	0·60	0·70	0·46	0·23	0·17	1·66
4·93	4·59	3·47	2·51	1·56	1·04	0·56	0·35	0·18	0·00	0·07	0·45	0·44	1·66
6·54	5·54	5·24	4·32	2·93	1·82	1·24	0·61	0·29	0·22	0·19	0·00	0·11	1·99
6·27	6·01	5·20	4·05	3·02	1·63	0·96	0·53	0·35	0·00	0·21	1·31	1·11	2·26
22·95	20·95	17·71	14·09	9·71	5·90	3·48	1·89	1·42	0·92	0·93	1·99	1·83	7·57
5·74	5·24	4·43	3·52	2·43	1·47	0·87	0·47	0·35	0·23	0·23	0·50	0·46	1·89
5·51	5·01	4·20	3·29	2·20	1·24	0·64	0·24	0·12	0·00	0·00	0·27	0·23	1·66

Java, Eastern Archipelago.

5·76	6·10	5·42	3·96	2·44	1·34	0·75	0·40	0·25	0·05	0·54	......	......	2·19
7·52	6·70	5·21	3·25	1·28	0·55	0·29	0·00	0·04	0·38	0·74	......	......	2·51
6·61	6·35	4·96	3·34	1·77	0·95	0·22	0·00	0·30	0·29	0·61	......	......	2·52
6·50	5·93	5·16	3·67	2·62	1·92	1·42	1·66	0·98	1·14	2·07	......	......	2·88
26·39	25·08	20·75	14·22	8·11	4·76	2·68	2·06	1·57	1·86	3·96	......	......	10·10
6·60	6·27	5·19	3·55	2·03	1·19	0·67	0·51	0·39	0·46	0·99	......	......	2·52
6·27	5·94	4·86	3·22	1·70	0·86	0·34	0·18	0·06	0·13	0·66	......	......	2·19

in Borneo, Eastern Archipelago.

6·49	6·00	4·95	3·66	2·28	1·21	0·32	0·02	0·15	0·00	0·03	0·23	0·32	2·09
7·08	6·55	5·06	4·17	2·49	1·51	1·21	0·00	0·20	0·20	0·44	0·45	0·56	2·39
6·08	5·79	4·92	3·98	1·69	1·58	1·06	0·51	0·71	0·47	0·03	0·00	0·22	2·12
19·65	18·34	14·93	11·81	6·66	4·30	2·59	0·53	1·06	0·67	0·50	0·68	1·10	6·60
6·55	6·11	4·98	3·94	2·22	1·43	0·86	0·18	0·35	0·22	0·17	0·23	0·37	2·20
6·38	5·94	4·81	3·77	2·05	1·26	0·69	0·01	0·18	0·05	0·00	0·06	0·20	2·03

Oscillation of the Horizontal Intensity at Padang in Sumatra,

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
October ......1847......	......	......	......	3·81	3·61	3·28	3·82	4·76	6·76	8·88	11·06
November	......	......	... ..	1·02	0·89	1·09	1·52	2·88	4·17	5·68	6·28
December	......	......	......	0·00	0·37	0·93	1·17	2·28	3·84	4·53	5·83
January ......1848......	......	......	......	2·36	2·00	2·04	2·62	3·17	4·26	6·40	7·70
Sums	......	......	......	7·18	6·87	7·34	9·13	13·09	19·03	25·49	30·87
Means	......	......	......	1·79	1·72	1·83	2·28	3·27	4·76	6·37	7·72
Oscillation	......	......	......	1·63	1·56	1·67	2·12	3·11	4·60	6·21	7·56

Oscillation of the Horizontal Intensity at Singapore,

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
November ...1848......	......	......	......	2·41	2·28	2·03	2·41	2·36	4·61	5·25	6·48
December	......	......	......	0·65	0·71	0·64	1·27	2·14	2·65	4·01	5·35
Means	......	......	......	1·53	1·49	1·33	1·84	2·25	3·63	4·63	5·91
Oscillation	......	......	......	1·53	1·49	1·33	1·84	2·25	3·63	4·63	5·91

Oscillation of the Horizontal Intensity at Singapore,

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
November ......1848...	......	......	......	1·95	1·59	1·41	1·81	1·96	5·03	6·55	9·19
December	......	......	......	0·00	0·14	0·05	0·38	0·86	2·76	4·98	7·28
Sums	......	......	......	1·95	1·73	1·56	2·19	2·82	7·79	11·53	16·47
Means	......	......	......	0·97	0·86	0·73	1·09	1·41	3·89	5·76	8·23
Oscillation	......	......	......	0·81	0·70	0·57	0·93	1·25	3·73	5·60	8·07

Mean Hourly Oscillation of the Horizontal Intensity

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
December	0·18	0·35	0·49	0·73	0·75	0·76	1·11	1·91	3·20	4·56	5·70
January	0·34	0·11	0·42	0·36	0·50	0·61	1·12	1·72	2·92	4·30	5·81
February	0·01	0·09	0·29	0·29	0·50	0·59	0·74	1·36	2·75	4·82	6·14
Sums	0·53	0·55	1·20	1·38	1·75	1·96	2·97	4·99	8·87	13·68	17·65
Means	0·18	0·18	0·40	0·46	0·58	0·65	0·99	1·66	2·96	4·56	5·88
Oscillation	0·13	0·13	0·35	0·41	0·53	0·60	0·94	1·61	2·91	4·51	5·83

Mean Hourly Oscillation of the Horizontal Intensity

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
March	0·23	0·39	0·37	0·45	0·57	0·59	0·61	1·43	3·13	5·07	6·56
April	0·00	0·20	0·48	0·61	0·73	0·82	1·12	2·35	4·28	6·34	8·12
May	0·16	0·21	0·21	0·19	0·31	0·49	1·21	2·32	4·03	5·49	6·52
Sums	0·39	0·80	1·06	1·25	1·61	1·90	2·94	6·10	11·44	16·90	21·20
Means	0·13	0·27	0·35	0·42	0·54	0·63	0·98	2·03	3·81	5·63	7·07
Oscillation	0·07	0·21	0·29	0·36	0·48	0·57	0·92	1·97	3·75	5·57	7·01

Mean Hourly Oscillation of the Horizontal Intensity

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
June	0·03	0·07	0·17	0·18	0·22	0·35	1·00	2·06	3·46	4·84	5·84
July	0·12	0·22	0·32	0·21	0·49	0·72	1·33	2·37	3·83	5·12	5·94
August	0·19	0·53	0·57	0·57	0·81	0·89	1·52	2·54	4·19	5·43	6·57
Sums	0·34	0·82	1·06	0·96	1·52	1·96	3·85	6·97	11·48	15·39	18·35
Means	0·11	0·27	0·35	0·32	0·51	0·65	1·28	2·32	3·83	5·13	6·12
Oscillation	0·08	0·24	0·32	0·29	0·48	0·62	1·25	2·29	3·80	5·10	6·09

Eastern Archipelago. In Scale Divisions $k=\cdot000240$.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
12·26	11·81	9·68	6·63	4·26	2·12	2·19	3·74	1·61	0·00	0·46	......	......	5·31
5·86	5·22	4·16	2·87	2·96	1·22	0·74	0·41	0·19	0·00	0·06	......	......	2·48
6·12	5·72	4·65	3·46	2·41	1·64	1·30	0·58	0·60	0·42	0·78	......	......	2·45
7·72	7·21	6·00	4·31	2·29	1·65	1·17	1·18	0·68	0·24	0·00	......	......	3·32
31·96	29·96	24·49	17·27	11·92	6·63	5·40	5·91	3·08	0·66	1·30	......	......	13·56
7·99	7·49	6·12	4·32	2·98	1·66	1·35	1·48	0·77	0·16	0·32	......	......	3·39
7·83	7·33	5·96	4·16	2·82	1·50	1·19	1·32	0·61	0·00	0·16	......	......	3·23

Eastern Archipelago. Portable Bifilar $k=\cdot000240$.

6·09	4·89	3·76	2·61	2·53	2·16	1·57	0·31	0·00	0·47	0·78	......	......	2·79
5·51	5·06	3·90	3·27	2·68	1·27	1·10	0·27	0·00	0·07	0·43	......	......	2·17
5·80	4·97	3·83	2·94	2·60	1·71	1·33	0·29	0·00	0·27	0·60	......	......	2·48
5·80	4·97	3·83	2·94	2·60	1·71	1·33	0·29	0·00	0·27	0·60	......	......	2·48

Eastern Archipelago. Observatory Bifilar $k=\cdot000197$.

9·13	7·45	6·32	4·17	3·35	2·88	2·08	0·60	0·00	0·37	0·66	......	......	3·62
7·65	7·14	5·47	3·86	2·67	1·49	0·93	0·32	0·32	0·00	0·00	......	......	2·44
16·78	14·59	11·79	8·03	6·02	4·37	3·01	0·92	0·32	0·37	0·66	......	......	6·06
8·39	7·29	5·89	4·01	3·01	2·18	1·50	0·46	0·16	0·18	0·33	......	......	3·03
9·23	7·13	5·73	3·85	2·85	2·02	1·34	0·30	0·00	0·02	0·17	......	......	2·87

in the Winter Months of 1843, 1844, 1845.

5·57	4·83	3·87	2·83	2·00	1·60	1·26	0·69	0·26	0·00	0·02	0·03	0·09	1·79
5·97	5·27	4·11	3·00	2·03	1·66	1·27	0·86	0·50	0·50	0·17	0·12	0·00	1·83
6·64	6·06	4·86	3·68	2·57	1·72	1·50	0·84	0·48	0·23	0·05	0·00	0·10	1·90
18·18	16·16	12·84	9·51	6·60	4·98	4·03	2·39	1·24	0·73	0·24	0·15	0·19	5·52
6·06	5·39	4·28	3·17	2·20	1·66	1·34	0·80	0·41	0·24	0·08	0·05	0·06	1·84
6·01	5·34	4·23	3·12	2·15	1·61	1·29	0·75	0·36	0·19	0·03	0·00	0·01	1·79

in the Spring Months of 1843, 1844, 1845.

7·09	6·71	5·11	3·45	2·21	1·62	1·28	0·80	0·42	0·19	0·05	0·00	0·08	2·03
8·19	7·25	5·65	3·96	2·47	1·76	1·27	0·95	0·69	0·29	0·18	0·24	0·10	2·45
6·72	6·00	4·71	3·56	2·20	1·21	0·72	0·67	0·52	0·41	0·22	0·20	0·00	2·04
22·00	19·96	15·47	10·97	6·88	4·59	3·27	2·42	1·63	0·89	0·45	0·44	0·18	6·52
7·33	6·65	5·16	3·66	2·29	1·53	1·09	0·81	0·54	0·30	0·15	0·15	0·06	2·17
7·27	6·59	5·10	3·60	2·23	1·47	1·03	0·75	0·48	0·24	0·09	0·09	0·00	2·11

in the Summer Months of 1843, 1844, 1845.

6·06	5·56	4·46	3·17	1·71	0·80	0·24	0·19	0·20	0·06	0·02	0·02	0·00	1·70
6·28	5·79	4·76	3·41	2·06	1·21	0·83	0·36	0·37	0·20	0·20	0·08	0·00	1·95
6·56	5·81	4·79	3·31	2·09	1·10	0·67	0·60	0·26	0·30	0·00	0·08	0·08	2·07
18·90	17·16	14·01	9·89	5·86	3·11	1·74	1·15	0·83	0·56	0·22	0·18	0·08	5·72
6·30	5·72	4·67	3·30	1·95	1·04	0·58	0·38	0·28	0·19	0·07	0·06	0·03	1·91
6·27	5·69	4·64	3·27	1·92	1·01	0·55	0·35	0·25	0·16	0·04	0·03	0·00	1·88

Mean Hourly Oscillation of the Horizontal Intensity in the

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
September	0·09	0·39	0·71	0·89	0·94	0·85	1·23	2·44	4·37	5·95	6·80
October	0·28	0·61	0·62	0·87	0·98	0·92	0·99	1·99	3·91	5·83	7·02
December	0·11	0·30	0·41	0·73	0·66	0·69	0·87	1·81	3·36	4·88	5·95
Sums	0·48	1·30	1·74	2·49	2·58	2·46	3·09	6·24	11·64	16·66	19·77
Means	0·16	0·43	0·58	0·83	0·86	0·82	1·03	2·08	3·88	5·55	6·59
Oscillation	0·15	0·42	0·57	0·82	0·85	0·81	1·02	2·07	3·87	5·54	6·58

Mean Hourly Oscillation of the Horizontal Intensity

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Winter	0·13	0·13	0·35	0·41	0·53	0·60	0·94	1·61	2·91	4·51	5·83
Spring	0·07	0·21	0·29	0·36	0·48	0·57	0·92	1·97	3·75	5·57	7·01
Summer	0·08	0·24	0·32	0·29	0·48	0·62	1·25	2·29	3·80	5·10	6·09
Autumn	0·15	0·42	0·57	0·82	0·85	0·81	1·02	2·07	3·87	5·54	6·58
Sums	0·43	1·00	1·53	1·88	2·34	2·60	4·13	7·94	14·33	20·72	25·51
Means	0·11	0·25	0·38	0·47	0·58	0·65	1·03	1·98	3·58	5·18	6·38
Oscillation	0·09	0·23	0·36	0·45	0·56	0·63	1·01	1·96	3·56	5·16	6·36

Mean Hourly Oscillation of the Horizontal Intensity

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
December	0·18	0·35	0·49	0·73	0·75	0·76	1·11	1·91	3·20	4·56	5·70
January	0·34	0·11	0·42	0·36	0·50	0·61	1·12	1·72	2·92	4·30	5·81
February	0·01	0·09	0·29	0·29	0·50	0·59	0·74	1·36	2·75	4·82	6·14
March	0·23	0·39	0·37	0·45	0·57	0·59	0·61	1·43	3·13	5·07	6·56
April	0·00	0·20	0·48	0·61	0·73	0·82	1·12	2·35	4·28	6·34	8·12
May	0·16	0·21	0·21	0·19	0·31	0·49	1·21	2·32	4·03	5·49	6·52
June	0·03	0·07	0·17	0·18	0·22	0·35	1·00	2·06	3·46	4·84	5·84
July	0·12	0·22	0·32	0·21	0·49	0·72	1·33	2·37	3·83	5·12	5·94
August	0·19	0·53	0·57	0·57	0·81	0·89	1·52	2·54	4·19	5·43	6·57
September	0·09	0·39	0.71	0·89	0·94	0·85	1·23	2·44	4·37	5·95	6·80
October	0·28	0·61	0·62	0·87	0·98	0·92	0·99	1·99	3·91	5·83	7·02
November	0·11	0·30	0·41	0·73	0·66	0·69	0·87	1·81	3·36	4·88	5·95
Sums	1·74	3·77	5·06	6·08	7·46	8·28	12·85	24·30	43·43	62·63	76·97
Means	0·14	0·31	0·42	0·51	0·62	0·69	1·07	2·02	3·62	5·22	6·41
Oscillation	0·08	0·25	0·36	0·46	0·56	0·63	1·01	1·96	3·56	5·16	6·35

Mean Oscillation of the Horizontal Intensity at Singapore

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
1843	0·06	0·22	0·31	0·35	0·49	0·54	0·94	1·90	3·38	4·94	6·17
1844	0·12	0·21	0·40	0·38	0·58	0·62	1·07	1·97	3·51	5·00	6·09
1845	0·13	0·29	0·45	0·53	0·69	0·79	1·10	2·09	3·86	5·60	6·86
Sums	0·31	0·72	1·16	1·26	1·76	1·95	3·11	5·96	10·75	15·54	19·12
Means	0·10	0·24	0·39	0·42	0·59	0·65	1·04	1·99	3·58	5·18	6·37
Oscillation	0·09	0·23	0·38	0·41	0·58	0·64	1·03	1·98	3·57	5·17	6·36

Comparison of Horizontal Intensity in minutes of Arc between the Fixed

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Bifilar Portable	......	......	......	2′·19	2′·13	1′·90	2′·63	3′·22	5′·19	6′·62	8′·45
Bifilar Fixed	......	......	......	0 ·88	0 ·75	0 ·61	1 ·00	1 ·35	4 ·02	6 ·04	8 ·70

Autumn Months of 1843, 1844, 1845. In Scale Divisions. $k=·000197$.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
6·76	5·53	3·89	2·29	1·76	1·10	0·63	0·52	0·44	0·12	0·04	0·00	0·15	2·00
7·26	6·14	4·42	2·98	2·11	1·78	1·49	0·80	0·46	0·18	0·00	0·01	0·10	2·15
5·88	5·02	4·00	2·83	1·89	1·33	0·90	0·51	0·26	0·11	0·02	0·03	0·00	1·77
19·90	16·69	12·31	8·10	5·76	4·21	3·02	1·83	1·16	0·41	0·06	0·04	0·25	5·92
6·63	5·56	4·10	2·70	1·92	1·40	1·01	0·61	0·39	0·14	0·02	0·01	0·08	1·97
6·62	5·55	4·09	2·69	1·91	1·39	1·00	0·60	0·38	0·13	0·01	0·00	0·07	1·96

in the four Seasons of 1843, 1844, 1845.

6·01	5·34	4·23	3·12	2·15	1·61	1·29	0·75	0·36	0·19	0·03	0·00	0·01	1·79
7·27	6·59	5·10	3·60	2·23	1·47	1·03	0·75	0·48	0·24	0·09	0·09	0·00	2·11
6·27	5·69	4·64	3·27	1·92	1·01	0·55	0·35	0·25	0·16	0·04	0·03	0·00	1·88
6·62	5·55	4·09	2·69	1·91	1·39	1·00	0·60	0·38	0·13	0·01	0·00	0·07	1·96
26·17	23·17	18·06	12·68	8·21	5·48	3·87	2·45	1·47	0·72	0·17	0·12	0·08	7·74
6·54	5·79	4·51	3·17	2·05	1·37	0·97	0·61	0·37	0·18	0·04	0·03	0·02	1·93
6·52	5·77	4·49	3·15	2·03	1·35	0·95	0·59	0·35	0·16	0·02	0·01	0·00	1·91

for each Month of the Years 1843, 1844, 1845.

5·57	4·83	3·87	2·83	2·00	1·60	1·26	0·69	0·26	0·00	0·02	0·03	0·09	1·79
5·97	5·27	4·11	3·00	2·03	1·66	1·27	0·86	0·50	0·50	0·17	0·12	0·00	1·83
6·64	6·06	4·86	3·68	2·57	1·72	1·50	0·84	0·48	0·23	0·05	0·00	0·10	1·90
7·09	6·71	5·11	3·45	2·21	1·62	1·28	0·80	0·42	0·19	0·05	0·00	0·08	2·03
8·19	7·25	5·65	3·96	2·47	1·76	1·27	0·95	0·69	0·29	0·18	0·24	0·10	2·45
6·72	6·00	4·71	3·56	2·20	1·21	0·72	0·67	0·52	0·41	0·22	0·20	0·00	2·04
6·06	5·56	4·46	3·17	1·71	0·80	0·24	0·19	0·20	0·06	0·02	0·02	0·00	1·70
6·28	5·79	4·76	3·41	2·06	1·21	0·83	0·36	0·37	0·20	0·20	0·08	0·00	1·95
6·56	5·81	4·79	3·31	2·09	1·10	0·67	0·60	0·26	0·30	0·00	0·08	0·08	2·07
6·76	5·53	3·89	2·29	1·76	1·10	0·63	0·52	0·44	0·12	0·04	0·00	0·15	2·00
7·26	6·14	4·42	2·98	2·11	1·78	1·49	0·80	0·46	0·18	0·00	0·01	0·10	2·15
5·88	5·02	4·00	2·83	1·89	1·33	0·90	0·51	0·26	0·11	0·02	0·03	0·00	1·77
78·98	69·97	54·63	38·47	25·10	16·89	12·06	7·79	4·86	2·59	0·97	0·81	0·70	23·68
6·58	5·83	4·55	3·21	2·10	1·41	1·01	0·65	0·41	0·22	0·08	0·07	0·06	1·97
6·52	5·76	4·49	3·15	2·04	1·35	0·95	0·59	0·35	0·16	0·02	0·01	0·00	1·91

during the three Years of 1843, 1844, 1845.

6·33	5·59	4·31	2·92	1·88	1·23	0·87	0·55	0·36	0·19	0·02	0·01	0·00	1·81
6·22	5·50	4·29	3·05	1·94	1·31	0·89	0·54	0·31	0·08	0·00	0·02	0·02	1·84
7·02	6·20	4·87	3·48	2·23	1·52	1·10	0·68	0·24	0·24	0·08	0·02	0·00	2·08
19·57	17·29	13·47	9·45	6·05	4·06	2·86	1·77	0·91	0·51	0·10	0·05	0·02	5·73
6·52	5·76	4·49	3·15	2·02	1·35	0·95	0·59	0·30	0·17	0·03	0·02	0·01	1·91
6·51	5·75	4·48	3·14	2·01	1·34	0·94	0·58	0·29	0·16	0·02	0·01	0·00	1·90

Observatory Bifilar and the Portable Bifilar at Singapore, Eastern Archipelago.

8′·29	7′·11	5′·48	4′·20	3′·72	2′·45	1′·90	0′·41	0′·00	0′·37	0′·86	……	……	3′·54
8·88	7·69	6·18	4·15	3·07	2·18	1·45	0·32	0·00	0·02	0·18	……	……	3·03

TABLE B.

Observatory at Moulmein.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Noon.	1.

k=·000415987 × cot 60°=·0002402.
q =·0002402.
Bifilar Magnetometer.

Sums	352·2	348·8	347·2	343·2	350·1	364·2	361·2	343·7	340·9	348·5	378·4
Means of 7 days	50·31	49·83	49·60	49·03	50·01	52·03	51·60	49·10	48·70	49·79	54·06
Temp. corrections	−0·73	−0·55	−0·05	0·00	−2·23	−8·34	−12·21	−16·61	−20·41	−23·64	−25·07
Corrected means	49·58	49·28	49·55	49·03	47·78	43·69	39·39	32·49	28·29	26·15	28·99
Oscillations & diffs.	0·00	0·30	0·03	0·55	1·80	5·89	10·19	17·09	21·29	23·43	20·59
$\frac{\delta X}{X}$	0·00	·00007	·00001	·00013	·00043	·00141	·00245	·00410	·00511	·00563	·00495

Thermometer of Bifilar.

Sums	536·1	534·9	531·4	531·0	547·3	589·4	616·5	647·3	673·9	696·5	706·5
Means of 7 days	76·59	76·41	75·91	75·86	78·19	84·20	88·07	92·47	96·27	99·50	100·93
Differences & corrs.	−0·73	−0·55	−0·05	0·00	−2·23	−8·34	−12·21	−16·61	−20·41	−23·64	−25·07

Observatory at Madras.—Hourly observations

k=·000415987 × cot 60°=·0002402.
q =·0002402.
Bifilar Magnetometer.

Sums	664·2	649·9	631·4	611·8	592·4	601·7	579·6	574·5	602·4	662·9	768·5
Means of 34 days	19·54	19·11	18·57	17·99	17·42	17·70	17·05	16·90	17·72	19·50	22·60
Temp. corrections	−1·27	−0·82	−0·39	0·00	−1·10	−4·43	−8·23	−10·90	−13·32	−15·28	−16·54
Corrected means	18·27	18·29	18·18	17·99	16·32	13·27	8·82	6·00	4·40	4·22	6·06
Oscillations & diffs.	0·28	0·26	0·37	0·56	2·23	5·28	9·73	12·55	14·15	14·33	12·49
$\frac{\delta X}{X}$	·00007	·00006	·00009	·00013	·00053	·00127	·00234	·00301	·00340	·00344	·00300

Thermometer of Bifilar.

Sums	2685·9	2670·8	2656·2	2642·7	2680·3	2793·5	2922·6	3013·4	3095·7	3162·5	3205·2
Means of 34 days	79·00	78·55	78·12	77·73	78·83	82·16	85·96	88·63	91·05	93·01	94·27
Differences & corrs.	−1·27	−0·82	−0·39	0·00	−1·10	−4·43	−8·23	−10·90	−13·32	−15·28	−16·54

TABLE B.

made during the Month of April, 1849.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
X=8·1186. Zero from the 14th to the 21st. Scale Divisions 51·72. Thermometer 80°·0.												
386·7	390·0	394·0	397·5	375·1	350·4	352·3	354·5	6878·9	362·0			
55·24	55·71	56·29	56·79	53·59	50·06	50·33	50·64	982·71	51·72	−8·1	43·6	+ ·001946
−26·50	−24·68	−22·47	−19·58	−12·31	−7·15	−5·30	−4·12					
28·74	31·03	33·82	37·21	41·28	42·91	45·03	46·52					
20·84	18·55	15·76	12·37	8·30	6·67	4·55	3·06					
·00501	·00446	·00379	·00297	·00199	·00160	·00109	·00073					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
716·5	703·8	688·3	668·1	617·2	581·1	568·1	559·8	11713·7	616·9			
102·36	100·54	98·33	95·44	88·17	83·01	81·16	79·98	1673·39	88·07	−8·1		
−26·50	−24·68	−22·47	−19·58	−12·31	−7·15	−5·30	−4·12					

made during the Month of August and September, 1849.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
X=8·0784. Zero from the 14th to the 21st. Scale Divisions 21·04. Thermometer 80°.												
862·2	878·7	886·1	842·4	817·2	795·9	792·1	776·7	13590·6	715·2			
25·36	25·84	26·06	24·78	24·04	23·41	23·30	22·85	399·74	21·04	−5·6	15·44	+ ·001345
−16·19	−14·70	−13·15	−10·74	−7·91	−5·83	−4·91	−4·30					
9·17	11·14	12·91	14·04	16·13	17·58	18·39	18·55					
9·38	7·41	5·64	4·51	2·42	0·97	0·16	0·00					
·00225	·00178	·00135	·00108	·00058	·00023	·00004	0·00					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
3193·4	3142·5	3089·9	3008·0	2911·8	2841·2	2809·8	2789·0	55314·4	2911·0			
93·92	92·43	90·88	88·47	85·64	83·56	82·64	82·03	1626·88	85·63	−5·6		
−16·19	−14·70	−13·15	−10·74	−7·91	−5·83	−4·91	−4·30					

TABLE B.

Observatory at Car Nicobar.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
$k = \cdot000415987 \times \cot 60° = \cdot0002402.$ $q \quad = \cdot0002402.$ Bifilar Magnetometer.											
Sums	458·8	457·9	456·1	454·1	460·3	463·8	462·0	456·5	458·6	457·9	455·4
Means of 5 days ...	91·76	91·58	91·22	90·82	92·06	92·76	92·40	91·30	91·72	91·58	91·08
Temp. corrections ...	0·00	−0·18	−0·40	−0·68	−1·08	−4·50	−8·04	−11·50	−13·70	−14·30	−15·02
Corrected means ...	91·76	91·40	90·82	90·14	90·98	88·26	84·36	79·80	78·02	77·28	76·06
Oscillations & diffs. .	+2·50	2·86	3·44	4·12	3·28	6·00	9·90	14·46	16·24	16·98	18·20
$\frac{\delta X}{X}$	·00060	·00069	·00083	·00099	·00079	·00144	·00238	·00347	·00390	·00408	·00437
Thermometer of Bifilar.											
Sums	365·3	366·2	367·3	368·7	370·7	387·8	405·5	422·8	433·8	436·8	440·4
Means of 5 days ...	73·06	73·24	73·46	73·74	74·14	77·56	81·10	84·56	86·76	87·36	88·08
Differences & corrs..	0·00	−0·18	−0·40	−0·68	−1·08	−4·50	−8·04	−11·50	−13·70	−14·30	−15·02

Observatory at Samboanga.—Hourly observations

$k = \cdot000415987 \times \cot 60° = \cdot0002402.$ $q \quad = \cdot0002402.$ Bifilar Magnetometer.											
Sums	787·0	786·0	785·7	781·0	790·9	813·5	817·4	808·1	792·1	792·3	800·4
Means of 6 days ...	131·17	131·00	130·95	130·17	131·82	135·58	136·23	134·68	132·02	132·05	133·40
Temp. corrections ...	−0·34	−0·15	−0·20	0·00	−3·52	−9·22	−11·95	−13·42	−12·44	−13·79	−14·99
Corrected means ...	130·83	130·85	130·75	130·17	128·30	126·36	124·28	121·26	119·58	118·26	118·41
Oscillations & diffs. .	0·02	0·00	0·10	0·68	2·55	4·49	6·57	9·59	11·27	12·59	12·44
$\frac{\delta X}{X}$	·00001	0·00	·00002	·00016	·00061	·00108	·00158	·00230	·00271	·00302	·00299
Thermometer of Bifilar.											
Sums	446·2	445·1	445·4	444·2	465·3	499·5	515·9	524·7	518·8	526·9	534·1
Means of 6 days ...	74·37	74·18	74·23	74·03	77·55	83·25	85·98	87·45	86·47	87·82	89·02
Differences & corrs..	−0·34	−0·15	−0·20	0·00	−3·52	−9·22	−11·95	−13·42	−12·44	−13·79	−14·99

Table B.

during the Month of February, 1849.

X=8·1555. Zero from the 6th to the 10th. Scale Divisions 94·52. Thermometer 80°.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
470·6	494·6	500·1	502·9	496·7	493·6	490·7	489·0	8979·6	472·6			
94·12	98·92	100·02	100·58	99·34	98·72	98·14	97·80	1795·92	94·52	−0·6	93·92	+ ·000144
−13·84	−12·98	−12·82	−11·64	−8·44	−5·94	−4·68	−3·54					
80·28	85·94	87·20	88·94	90·90	92·78	93·46	94·26					
13·98	8·32	7·06	5·32	3·36	1·48	0·80	0·00					
·00336	·00200	·00170	·00128	·00081	·00036	·00019	0·00					

$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
434·5	430·2	429·4	423·5	407·5	395·0	388·7	383·0	7657·1	403·1			
86·90	86·04	85·88	84·70	81·50	79·00	77·74	76·60	1531·42	80·60	−0·6		
−13·84	−12·98	−18·82	−11·64	−8·44	−5·94	−4·68	−3·54					

made during the Month of May, 1848.

X=8·162. Zero from the 25th to the 31st. Scale Divisions 134·62. Thermometer 80°.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
819·9	836·6	843·4	837·1	822·5	818·7	812·1	801·5	15346·2	807·7			
136·65	139·43	140·57	139·52	137·08	136·45	135·35	133·58	2557·70	134·62	−2·48	132·14	+ ·000596
−15·37	−14·59	−13·25	−10·94	−8·65	−7·05	−5·92	−4·70					
121·28	124·84	127·32	128·58	128·43	129·40	129·43	128·88					
9·57	6·01	3·53	2·27	2·42	1·45	1·42	1·97					
·00230	·00144	·00085	·00054	·00058	·00035	·00034	·00047					

$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
536·4	531·7	523·7	509·8	496·1	486·5	479·7	472·4	9402·4	494 9			
89·40	88·62	87·28	84·97	82·68	81·08	79·95	78·73	1567·06	82·48	−2·48		
−15·37	−14·59	−13·25	−10·94	−8·65	−7·05	−5·92	−4·70					

TABLE B.

Observatory at Penang.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
k=·000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.											
Sums	423·3	421·3	419·1	415·8	414·4	401·2	399·2	401·9	401·0	423·5	433·7
Means of 5 days	84·66	84·26	83·82	83·16	82·88	80·24	79·84	80·38	80·20	84·70	86·74
Temp. corrections	−1·22	−0·96	0·00	0·00	−0·96	−2·82	−6·64	−10·30	−12·94	−13·76	−12·62
Corrected means	83·44	83·30	83·82	83·16	81·92	77·42	73·20	70·08	67·26	70·94	74·12
Oscillations & diffs.	0·38	0·52	0·00	0·66	1·90	6·40	10·62	13·74	16·56	12·88	9·70
$\frac{\delta X}{X}$	·00009	·00012	0·000	·00016	·00046	·00154	·00255	·00330	·00398	·00309	·00233
Thermometer of Bifilar.											
Sums	381·1	379·8	375·0	375·0	379·8	389·1	408·2	426·5	439·7	443·8	438·1
Means of 5 days	76·22	75·96	75·00	75·00	75·96	77·82	81·64	85·30	87·94	88·76	87·62
Differences & corrs.	−1·22	−0·96	0·00	0·00	−0·96	−2·82	−6·64	−10·30	−12·94	−13·76	−12·62

Observatory at Pulo Dinding.—Hourly observations

k=·000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.											
Sums	168·4	166·4	165·5	162·9	159·9	161·6	166·3	172·0	177·8	182·3	191·5
Means of 2 days	84·20	83·20	82·75	81·45	79·95	80·80	83·15	86·00	88·90	91·15	95·75
Temp. corrections	−1·90	−1·10	−0·85	0·00	−0·20	−3·85	−9·30	−15·05	−19·15	−20·60	−21·20
Corrected means	82·30	82·10	81·90	81·45	79·75	76·95	73·85	70·95	69·75	70·55	74·55
Oscillations & diffs.	0·00	0·20	0·40	0·85	2·55	5·35	8·45	11·35	12·35	11·75	7·75
$\frac{\delta X}{X}$	0·00	·00005	·00009	·00020	·00061	·00128	·00203	·00273	·00301	·00282	·00186
Thermometer of Bifilar.											
Sums	150·8	149·2	148·7	147·0	147·4	154·7	165·6	177·1	185·3	188·2	189·4
Means of 2 days	75·40	74·60	74·35	73·50	73·70	77·35	82·80	88·55	92·65	94·10	94·70
Differences & corrs.	−1·90	−1·10	−0·85	0·00	−0·20	−3·85	−9·30	−15·05	−19·15	−20·60	−21·20

Table B.

made during the Month of January, 1849.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
X=8·159. Zero from the 22nd to the 26th. Scale Divisions 84·85. Thermometer 80°.												
448·1	461·1	449·5	442·6	435·3	427·9	423·1	418·5	8060·5	424·2			
89·62	92·22	89·90	88·52	87·06	85·58	84·62	83·70	1612·10	84·85	−1·42	83·43	+ ·000341
−11·02	−11·64	−9·92	−8·34	−6·68	−4·86	−3·94	−3·36					
78·60	80·58	79·98	80·18	80·38	80·72	80·68	80·34					
5·22	3·24	3·84	3·64	3·44	3·10	3·14	3·48					
·00125	·00078	·00092	·00087	·00081	·00074	·00075	·00084					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
430·1	433·2	424·6	416·7	408·4	399·3	394·7	391·8	7734·9	407·2			
86·02	86·64	84·92	83·34	81·68	79·86	78·94	78·36	1546·98	81·42	−1·42		
−11·02	−11·64	−9·92	−8·34	−6·68	−4·86	−3·94	−3·36					

made during the Month of January, 1849.

X=8·117. Zero from the 12th to the 13th. Scale Divisions 87·30. Thermometer 80°.												
193·5	192·4	187·2	181·2	174·3	172·3	172·4	169·5	3317·4	174·6			
96·75	96·20	93·60	90·60	87·15	86·15	86·20	84·75	1658·70	87·30	−2·55	84·75	+ ·000613
−19·30	−16·95	−12·65	−9·75	−7·00	−5·05	−4·15	−3·95					
77·45	79·25	80·95	80·85	80·15	81·10	82·05	80·80					
4·85	3·05	1·35	1·45	2·15	1·20	0·25	1·50					
·00116	·00073	·00032	·00035	·00052	·00029	·00006	·00036					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
185·6	180·9	172·3	166·5	161·0	157·1	155·3	154·9	3137·0	165·1			
92·80	90·45	86·15	83·25	80·50	78·55	77·65	77·45	1568·50	82·25	−2·55		
−19·30	−16·95	−12·65	−9·75	−7·00	−5·05	−4·15	−3·95					

TABLE B.

Observatory at Keemah.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
$k=\cdot000415987\times\cot 60^\circ=\cdot0002402.$ $q\qquad=\cdot0002402.$ Bifilar Magnetometer.											
Sums	587·5	583·7	581·3	573·4	578·4	556·5	629·8	636·8	588·6	602·8	644·8
Means of 10 days ...	58·75	58·37	58·13	57·34	57·84	61·83	62·98	63·68	65·40	66·98	64·48
Temp. corrections ...	−0·70	−0·44	−0·29	0·00	−1·91	−8·13	−11·62	−14·27	−17·00	−18·72	−15·17
Corrected means ...	58·05	57·93	57·84	57·34	55·93	53·70	51·36	49·41	48·40	48·26	49·31
Oscillations & diffs. .	0·00	0·12	0·21	0·71	2·12	4·35	6·69	8·64	9·65	9·79	8·74
$\frac{\delta X}{X}$	0·00	·00003	·00005	·00017	·00051	·00104	·00161	·00208	·00232	·00235	·00210
Thermometer of Bifilar.											
Sums	734·6	732·0	730·5	727·6	746·7	728·0	843·8	870·3	807·8	823·3	879·3
Means of 10 days ...	73·46	73·20	73·05	72·76	74·67	80·89	84·38	87·03	89·76	91·48	87·93
Differences & corrs. .	−0·70	−0·44	−0·29	0·00	−1·91	−8·13	−11·62	−14·27	−17·00	−18·72	−15·17

Observatory at Sarawak.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$k=\cdot000415987\times\cot 60^\circ=\cdot0002402.$ $q\qquad=\cdot0002402.$ Bifilar Magnetometer.													
Sums	2177·1	2166·3	2157·2	2145·2	2139·6	2130·4	2111·7	2085·4	2079·0	2093·8	2133·6	2179·1	2230·5
Means of 26 days ...	83·73	83·32	82·97	82·51	82·29	81·94	81·22	80·21	79·96	80·53	82·06	83·81	85·79
Temp. corrections ...	−1·50	−1·28	−1·03	−0·77	−0·47	−0·25	0·00	−0·02	−1·08	−3·25	−5·62	−7·58	−9·07
Corrected means ...	82·23	82·04	81·94	81·74	81·82	81·69	81·22	80·19	78·88	77·28	76·44	76·23	76·72
Oscillations & diffs. .	0·49	0·68	0·78	0·98	0·90	1·03	1·50	2·53	3·84	5·44	6·28	6·49	6·00
$\frac{\delta X}{X}$	·00012	·00016	·00019	·00023	·00022	·00025	·00036	·00061	·00092	·00131	·00151	·00156	·00144
Thermometer of Bifilar.													
Sums	2012·5	2006·7	2000·2	1993·4	1985·7	1979·9	1973·4	1973·8	2001·6	2057·9	2119·5	2170·4	2209·3
Means of 26 days ...	77·40	77·18	76·93	76·67	76·37	76·15	75·90	75·92	76·98	79·15	81·52	83·48	84·97
Differences & corrs. .	−1·50	−1·28	−1·03	−0·77	−0·47	−0·25	0·00	−0·02	−1·08	−3·25	−5·62	−7·58	−9·07

TABLE B.

made during the Months of June and July, 1848.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
X=8·253. Zero from the 21st to the 1st. Scale Divisions 61·86. Thermometer 80°.												
629·2	635·7	646·9	642·7	630·4	615·7	606·6	596·1	11566·9	617·9			
62·92	63·57	64·69	64·27	63·04	61·57	60·66	59·61	1176·11	61·86	−0·74	61·12	+·000178
−12·70	−11·31	−10·60	−8·94	−7·04	−5·82	−4·87	−4·05					
50·22	52·26	54·09	55·33	56·00	55·75	55·79	55·56					
7·83	5·79	3·96	2·72	2·05	2·30	2·26	2·49					
·00188	·00139	·00095	·00065	·00049	·00055	·00054	·00060					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
854·6	840·7	833·6	817·0	798·0	785·8	776·3	768·1	15098·0	807·2			
85·46	84·07	83·36	81·70	79·80	78·58	77·63	76·81	1536·02	80·74	−0·74		
−12·70	−11·31	−10·60	−8·94	−7·04	−5·82	−4·87	−4·05					

made during the Month of June, 1846.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Temp. Corrs.	Corr. Means.	$\frac{\delta X}{X}$.
X=8·186. Zero from the 1st to the 30th. Scale Divisions 84·58. Thermometer 80°.															
2275·2	2311·7	2328·6	2331·4	2326·8	2289·7	2249·9	2231·3	2215·4	2200·9	2189·0	52778·8	2199·3			
87·51	88·91	89·56	89·67	89·49	88·07	86·53	85·82	85·21	84·65	84·19	2029·95	84·58	+0·15	84·73	−·000036
−9·74	−9·85	−9·12	−8·16	−7·09	−5·37	−3·96	−3·10	−2·52	−2·16	−1·79					
77·77	79·06	80·44	81·51	82·40	82·70	82·57	82·72	82·69	82·49	82·40					
4·95	3·66	2·28	1·21	0·32	0·02	0·15	0·00	0·03	0·23	0·32					
·00119	·00088	·00055	·00029	·00008	·00001	·00004	0·00	·00001	·00005	·00008					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$															
2226·6	2229·5	2210·5	2185·5	2157·8	2113·0	2076·4	2053·9	2038·8	2029·6	2020·0	49825·9	2075·9			
85·64	85·75	85·02	84·06	82·99	81·27	79·86	79·00	78·42	78·06	77·69	1916·38	79·85	+0·15		
−9·74	−9·85	−9·12	−8·16	−7·09	−5·37	−3·96	−3·10	−2·52	−2·16	−1·79					

Table B.

Observatory at Sarawak.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
q=·000415987 × cot 60°=·0002402. k =·0002402. Bifilar Magnetometer.													
Sums	2351·3	2333·3	2318·5	2310·1	2303·6	2293·2	2274·6	2247·7	2223·9	2237·4	2260·5	2302·4	2360·5
Means of 27 days	87·09	86·42	85·87	85·56	85·32	84·93	84·24	83·25	82·37	82·87	83·72	85·27	87·43
Temp. corrections	−1·77	−1·43	−1·11	−0·78	−0·61	−0·53	−0·20	0·00	−0·87	−2·84	−4·78	−6·52	−8·15
Corrected means	85·32	84·99	84·76	84·78	84·71	84·40	84·04	83·25	81·50	80·03	78·94	78·75	79·28
Oscillations & diffs.	0·51	0·84	1·07	1·05	1·12	1·43	1·79	2·58	4·33	5·80	6·89	7·08	6·55
$\frac{\delta X}{X}$	·00012	·00020	·00026	·00025	·00027	·00034	·00043	·00062	·00104	·00139	·00165	·00170	·00157
Thermometer of Bifilar.													
Sums	2082·4	2073·2	2064·8	2055·8	2051·3	2049·1	2040·2	2034·6	2058·2	2111·3	2163·8	2210·7	2254·8
Means of 27 days	77·13	76·79	76·47	76·14	75·97	75·89	75·56	75·36	76·23	78·20	80·14	81·88	83·51
Differences & corrs.	−1·77	−1·43	−1·11	−0·78	−0·61	−0·53	−0·20	0·00	−0·87	−2·84	−4·78	−6·52	−8·15

Observatory at Sarawak.—Hourly observations

k=·000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.													
Sums	1709·9	1705·6	1694·5	1686·8	1676·4	1670·7	1659·8	1645·8	1643·5	1651·3	1681·0	1711·4	1751·0
Means of 19 days	89·99	89·77	89·18	88·78	88·23	87·93	87·36	86·62	86·50	86·91	88·47	90·07	92·16
Temp. corrections	−1·64	−1·38	−1·05	−0·76	−0·58	−0·38	−0·10	0·00	−0·95	−3·22	−5·47	−7·25	−9·05
Corrected means	88·35	88·39	88·13	88·02	87·65	87·55	87·26	86·62	85·55	83·69	83·00	82·82	83·11
Oscillations & diffs.	0·55	0·51	0·77	0·88	1·25	1·35	1·64	2·28	3·35	5·21	5·90	6·08	5·79
$\frac{\delta X}{X}$	·00013	·00012	·00018	·00021	·00030	·00032	·00039	·00055	·00080	·00125	·00142	·00146	·00139
Thermometer of Bifilar.													
Sums	1455·8	1450·9	1444·6	1439·0	1435·7	1431·8	1426·6	1424·6	1442·6	1485·8	1528·5	1562·4	1596·6
Means of 19 days	76·62	76·36	76·03	75·74	75·56	75·36	75·08	74·98	75·93	78·20	80·45	82·23	84·03
Differences & corrs.	−1·64	−1·38	−1·05	−0·76	−0·58	−0·38	−0·10	0·00	−0·95	−3·22	−5·47	−7·25	−9·05

Table B.

made during the Month of July, 1846.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Temp. Corrs.	Corr. Means.	$\frac{\delta X}{X}$.

Zero from the 1st to the 31st. Scale Divisions 87·26. Thermometer 80°.

2417·5	2454·1	2483·2	2496·5	2479·1	2474·3	2419·6	2398·3	2379·4	2368·6	2355·7	56543·3	2355·7			—
89·54	90·89	91·97	92·46	91·82	91·64	89·61	88·83	88·13	87·73	87·25	2094·21	87·26	+0·82	88·08	·000197
−8·87	−9·23	−8·63	−8·14	−7·20	−5·81	−3·98	−3·20	-2·74	−2·35	−1·98					
80·67	81·66	83·34	84·32	84·62	85·83	85·63	85·63	85·39	85·38	85·27					
5·06	4·17	2·49	1·51	1·21	0·00	0·20	0·20	0·44	0·45	0·56					
·00124	·00100	·00060	·00036	·00029	0·00	·00005	·00005	·00011	·00011	·00013					

$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$

2274·2	2284·0	2267·7	2254·4	2229·1	2191·6	2142·3	2121·2	2108·8	2098·1	2088·1	51309·7	2137·9			
84·23	84·59	83·99	83·50	82·56	81·17	79·34	78·56	78·10	77·71	77·34	1900·36	79·18	+0·82		
−8·87	−9·23	−8·63	−8·14	−7·20	−5·81	−3·98	−3·20	−2·74	−2·35	−1·98					

made during the Month of August, 1846.

Zero from the 1st to the 22nd. Scale Divisions 90·83. Thermometer 80°.

1793·5	1816·0	1831·9	1818·8	1805·8	1789·9	1655·0	1645·5	1645·2	1641·5	1632·0	40963·7	1725·3			—
94·39	95·63	76·42	95·73	95·04	94·21	91·94	91·42	91·40	91·19	90·67	2180·01	90·83	+0·91	91·74	·000219
−10·41	−10·71	−10·21	−8·41	−7·20	−5·85	−3·75	−2·99	−2·53	−2·29	−1·99					
83·98	84·92	86·21	87·32	87·84	88·36	88·19	88·43	88·87	88·90	88·68					
4·92	3·98	1·69	1·58	1·06	0·54	0·71	0·47	0·03	0·00	0·22					
·00118	·00095	·00041	·00038	·00040	·00013	·00017	·00011	·00001	0·00	·00005					

$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$

1622·4	1628·1	1618·6	1584·5	1561·5	1535·8	1417·1	1403·5	1395·2	1390·8	1385·4	35667·8	1503·1			
85·39	85·69	85·19	83·39	82·18	80·83	78·73	77·97	77·51	77·27	76·97	1897·69	79·09	+0·91		
−10·41	−10·71	−10·21	−8·41	−7·20	−5·85	−3·75	−2·99	−2·53	−2·29	−1·99					

TABLE B.

Observatory at Pulo Peesang.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
k=·000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.											
Sums	……	……	270·0	340·9	340·4	344·5	351·5	369·6	386·8	389·8	398·1
Means of 5 days	……	……	67·50	68·18	68·08	68·90	70·30	73·92	77·36	77·96	79·62
Temp. corrections	……	……	−2·35	0·00	−1·14	−3·52	−7·94	−12·44	−15·04	−14·78	−14·60
Corrected means	……	……	65·15	68·18	66·94	65·38	62·36	61·48	62·32	63·18	65·02
Oscillations & diffs.	……	……	3·23	0·20	1·44	3·00	6·02	6·90	6·06	5·20	3·36
$\frac{\delta X}{X}$	……	……	·00078	·00005	·00035	·00072	·00145	·00166	·00146	·00125	·00081
Thermometer of Bifilar.											
Sums	……	……	310·9	376·9	382·6	394·5	416·6	439·1	452·1	450·8	449·9
Means of 5 days	……	……	77·73	75·38	76·52	78·90	83·32	87·82	90·42	90·16	89·98
Differences & corrs.	……	……	−2·35	0·00	−1·14	−3·52	−7·94	−12·44	−15·04	−14·78	−14·60

Observatory at Singapore.—Hourly observations

k=·000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer No. I.											
Sums	1881·6	1880·9	1879·6	1872·1	1899·2	1900·5	1928·7	1942·2	1967·2	1992·3	2002·5
Means of 16 days	117·60	117·56	117·48	117·01	118·70	118·78	120·54	121·39	122·95	124·52	125·16
Temp. corrections	−0·59	−0·42	−0·09	0·00	−1·64	−3·97	−6·37	−8·45	−9·62	−9·99	−9·50
Corrected means	117·01	117·14	117·39	117·01	117·06	114·81	114·17	112·94	113·33	114·53	115·66
Oscillations & diffs.	2·41	2·28	2·03	2·41	2·36	4·61	5·25	6·48	6·09	4·89	3·76
$\frac{\delta X}{X}$	·00058	·00055	·00049	·00058	·00057	·00111	·00126	·00156	·00146	·00117	·00090
Thermometer of Bifilar No. I.											
Sums	1207·6	1204·9	1199·6	1198·2	1224·4	1261·7	1300·2	1333·5	1352·1	1358·1	1350·2
Means of 16 days	75·48	75·31	74·98	74·89	76·53	78·86	81·26	83·34	84·51	84·88	84·39
Differences & corrs.	−0·59	−0·42	−0·09	0·00	−1·64	−3·97	−6·37	−8·45	−9·62	−9·99	−9·50

TABLE B.

Month of January, 1846.

	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
X=8·092. Zero from the 18th to the 22nd. Scale Divisions 72·18. Thermometer 80°.													
	388·8	373·2	366·2	289·3	345·9	342·5	279·6	211·8	5918·6	360·2			
	77·76	74·64	73·24	72·33	69·18	68·50	69·90	70·60	1292·82	72·18	−2·17	70·01	+ ·000521
	−11·42	−8·12	−7·08	−5·07	−2·98	−2·50	−3·00	−2·22					
	66·34	66·52	66·16	67·26	66·20	66·00	66·90	68·38					
	2·04	1·86	2·22	1·12	2·18	2·38	1·48	0·00					
	·00049	·00045	·00053	·00027	·00052	·00057	·00035	0·000					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$													
	434·0	417·5	412·3	321·8	391·8	389·4	313·5	232·8	6738·3	410·8			
	86·80	83·50	82·46	80·45	78·36	77·88	78·38	77·60	1471·56	82·17	−2·17		
	−11·42	−8·12	−7·08	−5·07	−2·98	−2·50	−3·00	−2·22					

Month of November, 1848.

	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
X=8·115. Zero from the 13th to the 30th. Scale Divisions 121·82. Thermometer 80°.													
	2014·3	2004·5	2001·6	1999·9	1986·7	1975·9	1956·4	1946·0	37032·1	1949·0			
	125·89	125·28	125·10	124·99	124·17	123·49	122·28	121·63	2314·52	121·82	−0·07	121·75	+ ·000017
	−9·08	−8·39	−7·84	−7·14	−5·06	−4·07	−3·33	−2·99					
	116·81	116·89	117·26	117·85	119·11	119·42	118·95	118·64					
	2·81	2·53	2·16	1·57	0·31	0·00	0·47	0·78					
	·00063	·00061	·00052	·00038	·00007	0·00	·00011	·00019					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$													
	1343·5	1332·4	1323·7	1312·5	1279·2	1263·3	1251·5	1246·0	24342·6	1281·1			
	83·97	83·28	82·73	82·03	79·95	78·96	78·22	77·88	1521·45	80·07	−0·07		
	−9·08	−8·39	−7·84	−7·14	−5·06	−4·07	−3·33	−2·99					

TABLE B.

Observatory at Singapore.—Hourly observations

k=·0003136 × cot 58° 10′ 30″=·0001969.
q =·000214.

Bifilar Magnetometer No. II.

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
Sums	513·2	515·3	517·7	509·5	503·1	454·7	435·6	402·3	411·1	442·4	465·5
Means of 16 days ...	32·08	32·21	32·36	31·84	31·44	28·42	27·23	25·14	25·70	27·65	29·09
Temp. corrections ...	—0·63	—0·40	—0·37	—0·25	0·00	—0·07	—0·38	—0·93	—1·43	—1·70	—2·01
Corrected Means ...	31·45	31·81	31·99	31·59	31·44	28·37	26·85	24·21	24·27	25·95	27·08
Oscillations & diffs. .	1·95	1·59	1·41	1·81	1·96	5·03	6·55	9·19	9·13	7·45	6·32
$\frac{\delta X}{X}$	·00038	·00031	·00028	·00036	·00039	·00099	·00129	·00181	·00180	·00147	·00124

Thermometer of Bifilar No. II.

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
Sums	1276·6	1273·2	1272·6	1271·0	1267·3	1268·3	1273·0	1281·1	1288·4	1292·4	1297·0
Means of 16 days ...	79·79	79·58	79·54	79·44	79·21	79·27	79·56	80·07	80·53	80·78	81·06
Differences...........	—0·58	—0·37	—0·34	—0·23	0·00	—0·06	—0·35	—0·86	—1·32	—1·57	—1·85
Corrections	—0·63	—0·40	—0·37	—0·25	0·00	—0·07	—0·38	—0·93	—1·43	—1·70	—2·01

Observatory at Singapore.—Hourly observations

k=·000415987 × cot 60°=·0002402.
q =·0002402.

Bifilar Magnetometer No. I.

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
Sums	1696·8	1690·6	1685·1	1674·8	1685·2	1732·5	1755·5	1755·4	1769·1	1782·7	1795·6
Means of 14 days ...	121·20	120·76	120·36	119·63	120·37	123·75	125·39	125·39	126·36	127·34	128·26
Temp. corrections ...	—0·95	—0·57	—0·10	—0·00	—1·61	—5·50	—8·50	—9·84	—10·97	—11·50	—11·26
Corrected Means ...	120·25	120·19	120·26	119·63	118·76	118·25	116·89	115·55	115·39	115·84	117·00
Oscillations & diffs. .	0·65	0·71	0·64	1·27	2·14	2·65	4·01	5·35	5·51	5·06	3·90
$\frac{\delta X}{X}$	·00016	·00017	·00015	·00030	·00051	·00064	·00096	·00128	·00132	·00122	·00094

Thermometer of Bifilar No. I.

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
Sums	1055·4	1050·2	1043·5	1042·2	1064·7	1119·1	1161·1	1179·9	1195·8	1203·2	1199·8
Means of 14 days ...	75·39	75·01	74·54	74·44	76·05	79·94	82·94	84·28	85·41	85·94	85·70
Correction & differs.	—0·95	—0·57	—0·10	0·00	—1·61	—5·50	—8·50	—9·84	—10·97	—11·50	—11·26

Table B.

made during the Month of November, 1848.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
Zero from the 13th to the 30th. Scale Divisions 30·91. Thermometer 80°.												
501·8	513·3	518·4	529·4	549·1	557·6	547·7	535·6	9423·3	496·2			
31·36	32·08	32·40	33·09	34·32	34·85	34·23	33·48	586·76	30·91	−0·24	30·67	+ ·000047
−2·13	−2·03	−1·88	−1·77	−1·52	−1·45	−1·16	−0·74					
29·23	30·05	30·52	31·32	32·80	33·40	33·07	32·74					
4·17	3·35	2·88	2·08	0·60	0·00	0·37	0·66					
·00082	·00066	·00057	·00041	·00012	0·00	·00007	·00013					
$\frac{q}{k}=\frac{\cdot000214}{\cdot000197}=1\cdot086.$												
1298·7	1297·2	1295·0	1293·4	1289·8	1288·7	1284·5	1278·3	24386·5	1283·4			
81·17	81·08	80·94	80·84	80·61	80·54	80·28	79·89	1524·18	80·22	−0·22		
−1·96	−1·87	−1·73	−1·63	−1·40	−1·33	−1·07	−0·68					
−2·13	−2·03	−1·88	−1·77	−1·52	−1·45	−1·16	−0·74					

made during the Month of December, 1848.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
Zero from the 1st to the 16th. Scale Divisions 124·90. Thermometer 80°.												
1792·0	1807·3	1809·0	1788·1	1767·0	1755·1	1746·1	1735·4	33223·3	1748·8			
128·00	129·09	129·21	127·72	126·21	125·36	124·72	123·96	2373·08	124·90	−0·61	124·29	+ ·000146
−10·37	−10·87	−9·58	−7·92	−5·78	−4·46	−3·89	−3·49					
117·63	118·22	119·63	119·80	120·63	120·90	120·83	120·47					
3·27	2·68	1·27	1·10	0·27	0·00	0·07	0·43					
·00078	·00064	·00030	·00026	·00006	0·00	·00002	·00010					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
1187·4	1194·3	1176·3	1153·1	1123·1	1104·6	1096·6	1091·0	21441·3	1128·4			
84·81	85·31	84·02	82·36	80·22	78·90	78·33	77·93	1531·52	80·61	−0·61		
−10·37	−10·87	−9·58	−7·92	−5·78	−4·46	−3·89	−3·49					

TABLE B.

Observatory at Singapore.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
k=·0003136 × cot 58° 10′ 30″=·0001969. q =·000214.											Bifilar Magnetometer No. II.
Sums	387·2	384·8	384·5	376·8	340·5	342·0	317·7	293·5	293·8	306·7	333·1
Means of 14 days ...	27·66	27·49	27·46	26·91	26·19	24·43	22·69	20·96	20·99	21·91	23·79
Temp. corrections ...	−0·61	−0·58	−0·46	−0·24	0·00	−0·14	−0·62	−1·19	−1·59	−2·00	−2·21
Corrected means ...	27·05	26·91	27·00	26·67	26·19	24·29	22·07	19·77	19·40	19·91	21·58
Oscillations & diffs. .	0·00	0·14	0·05	0·38	0·86	2·76	4·98	7·28	7·65	7·14	5·47
$\frac{\delta X}{X}$	0·00	·00003	·00001	·00007	·00017	·00054	·00098	·00143	·00151	·00141	·00108
											Thermometer of Bifilar No. II.
Sums	1110·0	1109·7	1108·2	1105·3	1102·2	1104·1	1110·2	1117·5	1122·6	1128·1	1130·7
Means of 14 days ...	79·29	79·26	79·16	78·95	78·73	78·86	79·30	79·82	80·19	80·58	80·76
Differences	−0·56	−0·53	−0·43	−0·22	0·00	−0·13	−0·57	−1·09	−1·46	−1·85	−2·03
Corrections...........	−0·61	−0·58	−0·46	−0·24	0·00	−0·14	−0·62	−1·19	−1·59	−2·00	−2·21

Observatory at Carimon Island.—Hourly observations

k=·000415987 × cot 60°=·0002402. q =·0002402.											Bifilar Magnetometer.
Sums	......	......	442·4	525·5	533·9	541·0	548·1	557·5	577·0	597·4	602·3
Means of 6 days......	......	......	88·48	87·58	88·98	90·17	91·35	92·92	96·17	99·57	100·38
Temp. corrections ...	......	......	−0·29	0·00	−2·80	−5·77	−9·02	−10·92	−13·88	−13·88	−13·95
Corrected means ...	......	......	88·19	87·58	86·18	84·40	82·33	82·00	82·29	85·69	86·43
Oscillations & diffs. .	......	......	0·46	1·07	2·47	4·25	6·32	6·65	6·36	2·96	2·22
$\frac{\delta X}{X}$	......	......	·00011	·00026	·00059	·00102	·00152	·00160	·00153	·00071	·00053
											Thermometer of Bifilar.
Sums	......	......	384·2	459·3	476·1	493·9	513·4	524·8	542·6	542·6	543·0
Means of 6 days ...	......	......	76·84	76·55	79·35	82·32	85·57	87·47	90·43	90·43	90·50
Differences & corrs.	......	......	0·29	0·00	−2·80	−5·77	−9·02	−10·92	−13·88	−13·88	−13·95

TABLE B.

made during the Month of December, 1848.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
Zero from the 1st to the 16th. Scale Divisions 25·9. Thermometer 80°.												
355·0	372·1	388·6	393·6	397·5	401·5	397·1	393·2	6859·2	362·3			
25·36	26·58	27·76	28·11	28·39	28·68	28·36	28·09	491·81	25·88	+0·13	26·01	−·000026
−2·17	−2·20	−2·20	−1·99	−1·66	−1·93	−1·31	−1·04					
23·19	24·38	25·56	26·12	26·73	26·75	27·05	27·05					
3·86	2·67	1·49	0·93	0·32	0·32	0·00	0·00					
·00076	·00052	·00029	·00018	·00006	·00006	0·00	0·00					
$\frac{q}{k}=\frac{\cdot000214}{\cdot000197}=1\cdot1.$												
1130·2	1130·7	1130·7	1127·9	1123·7	1121·5	1119·1	1115·7	21248·1	1118·4			
80·73	80·76	80·76	80·56	80·26	80·11	79·94	79·69	1517·71	79·88	+0·12		
−2·00	−2·03	−2·03	−1·83	−1·53	−1·78	−1·21	−0·96					
−2·17	−2·20	−2·20	−1·99	−1·66	−1·93	−1·31	1·04					

made during the Month of January, 1846.

X=8·077. Zero from the 26th to the 31st. Scale Divisions 94·67. Thermometer 80°.												
611·6	606·9	598·9	584·6	565·0	553·4	548·3	8993·8	568·0				
101·93	101·15	99·82	97·43	94·17	92·23	91·38	1513·71	94·67	−4·7	90·0	+·001122	
−14·18	−12·72	−11·17	−9·05	−5·85	−3·72	−2·77						
87·75	88·43	88·65	88·38	88·32	88·51	88·61						
0·90	0·22	0·00	0·27	0·33	0·14	0·04						
·00022	·00005	0·00	·00006	·00008	·00003	·00001						
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
544·4	535·6	526·3	513·6	494·4	481·6	475·9	8051·7	508·7				
90·73	89·27	87·72	85·60	82·40	80·27	79·32	1354·77	84·75				
−14·18	−12·72	−11·17	−9·05	−5·85	−3·72	−2·77						

TABLE B.

Observatory at Pulo Booaya.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
k=·000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.											
Sums	......	......	237·4	235·5	231·6	233·0	230·3	233·4	239·7	250·7	335·8
Means of 3 & 4 days	......	......	79·13	78·50	77·20	77·67	76·77	77·80	79·90	83·57	83·95
Temp. corrections ...	......	......	0·00	−0·24	−0·60	−2·67	−3·67	−4·87	−5·64	−7·10	−5·87
Corrected means ...	......	......	79·13	78·26	76·60	75·00	73·10	72·93	74·26	76·47	78·08
Oscillations & diffs.	......	......	2·28	3·15	4·81	6·41	8·31	8·48	7·15	4·94	3·33
$\frac{\delta X}{X}$	......	......	·00055	·00076	·00116	·00154	·00200	·00204	·00172	·00119	·00080
Thermometer of Bifilar.											
Sums	......	......	240·4	241·1	242·2	248·4	251·4	255·0	257·3	261·7	344·0
Means of 3 & 4 days	......	......	80·13	80·37	80·73	82·80	83·80	85·00	85·77	87·23	86·00
Differences & corrs...	......	......	0·00	−0·24	−0·60	−2·67	−3·67	−4·87	−5·64	−7·10	−5·87

Observatory at Padang.—Hourly observations

k=·000416 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.											
Sums	1302·8	1302·6	1304·2	1195·6	1309·3	1340·8	1369·4	1386·2	1390·3	1413·6	1444·0
Means of 3 & 4 days	100·22	100·20	100·31	99·63	100·72	103·13	105·34	106·63	106·95	108·74	111·08
Temp. corrections ...	0·58	0·36	0·14	0·00	2·03	6·44	10·77	14·24	15·76	17·10	17·31
Corrected means ...	99·64	99·84	100·17	99·63	98·69	96·69	94·57	92·39	91·19	91·64	93·77
Oscillations & diffs.	3·81	3·61	3·28	3·82	4·76	6·76	8·88	11·06	12·26	11·81	9·68
$\frac{\delta X}{X}$	·00091	·00087	·00079	·00092	·00114	·00162	·00213	·00266	·00294	·00289	·00233
Thermometer of Bifilar.											
Sums	948·8	945·7	942·9	868·7	967·5	1024·8	1081·1	1126·2	1145·9	1163·4	1166·1
Means of 13 days ...	72·97	72·75	72·53	72·39	74·42	78·83	83·16	86·63	88·15	89·49	89·70
Differences & corrs.	0·58	0·36	0·14	0·00	2·03	6·44	10·77	14·24	15·76	17·10	17·31

TABLE B.

made during the Month of February 1846.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
Zero from the 6th to the 9th. Scale Divisions 81·81. Thermometer 80°.												
342·7	350·1	351·9	341·0	331·3	331·0	247·2	......	4522·6	330·1			
85·68	87·53	87·98	85·25	82·83	82·75	82·40	......	1308·91	81·81	−4·01	77·80	+ ·000963
−7·07	−8·12	−6·57	−4·59	−2·22	−1·77	−1·07	......					
78·61	79·41	81·41	80·66	80·61	80·98	81·33	......					
2·80	2·00	0·00	0·75	0·80	0·43	0·08	......					
·00067	·00048	0·00	·00018	·00019	·00010	·00002	......					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
348·8	353·0	346·8	338·9	329·4	327·6	162·4	......	......	4548·4	337·6		
87·20	88·25	86·70	84·72	82·35	81·90	81·20	......	......	1344·15	84·01	−4·01	
−7·07	−8·12	−6·57	−4·59	−2·22	−1·77	−1·07	......	......				

made during the Month of October, 1847.

X=7·962. Zero from the 16th to the 31st. Scale Divisions 106·42. Thermometer 80°.												
1476·8	1473·1	1482·8	1444·3	138·50	1389·2	1393·7	1376·4	26180·1	1383·5			
113·60	113·32	114·06	111·10	106·54	106·86	107·21	105·88	2021·52	106·42	−0·72	105·70	+ ·000173
16·78	14·13	12·73	9·84	6·83	5·02	3·76	2·89					
96·82	99·19	101·33	101·26	99·71	101·84	103·45	102·99					
6·63	4·26	2·12	2·19	3·74	1·61	0·00	0·46					
·00159	·00102	·00051	·00053	·00090	·00039	0·00	·00011					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
1159·2	1137·8	1106·5	1069·0	1029·8	1006·3	989·9	973·7	19858·3	1049·3			
89·17	87·52	85·12	82·23	79·22	77·41	76·15	75·28	1533·12	80·72			
16·78	14·13	12·73	9·84	6·83	5·02	3·76	2·89					

TABLE B.

Observatory at Padang.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.

$k=\cdot 000416 \times \cot 60^\circ = \cdot 0002402.$
$q = \cdot 0002402.$
Bifilar Magnetometer.

Sums	2525·1	2624·7	2516·4	2608·9	2629·1	2705·4	2785·3	2825·2	2891·2	2941·9	2975·4
Means of 26 days ...	101·00	100·95	100·66	100·34	101·12	104·05	107·13	108·66	111·20	113·15	114·44
Temp. corrections ...	0·27	0·09	0·00	0·11	2·25	6·47	11·06	13·19	15·31	16·62	16·85
Corrected means ...	100·73	100·86	100·66	100·23	98·87	97·58	96·07	95·47	95·89	96·53	97·59
Oscillations & diffs.	1·02	0·89	1·09	1·52	2·88	4·17	5·68	6·28	5·86	5·22	4·16
$\frac{\delta X}{X}$	·00024	·00021	·00026	·00036	·00069	·00100	·00136	·00151	·00141	·00125	·00100

Thermometer of Bifilar.

Sums	1828·5	1897·0	1821·7	1897·4	1953·1	2062·8	2182·2	2237·6	2292·7	2326·7	2332·7
Means of 26 days ...	73·14	72·96	72·87	72·98	75·12	79·34	83·93	86·06	88·18	89·49	89·72
Differences & corrs..	0·27	0·09	0·00	0·11	2·25	6·47	11·06	13·19	15·31	16·62	16·85

Observatory at Padang.—Hourly observations

$k=\cdot 000415987 \times \cot 60^\circ = \cdot 0002402.$
$q = \cdot 0002402.$
Bifilar Magnetometer.

Sums	2814·5	2794·7	2774·5	2768·6	2766·1	2821·2	2927·7	2994·3	3045·4	3116·6	3162·0
Means of 26 days ...	108·25	107·49	106·71	106·48	106·39	108·51	112·60	115·17	117·13	119·87	121·62
Temp. corrections ...	0·61	0·22	0·00	0·01	1·03	4·71	9·49	13·36	15·61	17·95	18·63
Corrected means ...	107·64	107·27	106·71	106·47	105·36	103·80	103·11	101·81	101·52	101·92	102·99
Oscillations & diffs.	0·00	0·37	0·93	1·17	2·28	3·84	4·53	5·83	6·12	5·72	4·65
$\frac{\delta X}{X}$	·000	·00009	·00022	·00028	·00055	·00092	·00109	·00140	·00147	·00137	·00112

Thermometer of Bifilar.

Sums	1914·9	1904·8	1899·1	1899·2	1925·9	2021·6	2145·8	2246·3	2304·8	2365·7	2383·5
Means of 26 days ...	73·65	73·26	73·04	73·05	74·07	77·75	82·53	86·40	88·65	90·99	91·67
Differences & corrs..	0·61	0·22	0·00	0·01	1·03	4·71	9·49	13·36	15·61	17·95	18·63

Table B.

made during the Month of November, 1847.

Zero from the 1st to the 30th. Scale Divisions 107·32. Thermometer 80°.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
2977·4	2935·2	2927·8	2877·8	2811·4	2774·6	2747·5	2721·0	52801·3	2790·0			
114·52	112·89	112·61	110·68	108·13	106·72	105·67	104·65	2038·57	107·32	−0·93	106·39	+ ·000223
15·64	14·10	12·08	9·67	6·79	5·16	3·92	2·96					
98·88	98·79	100·53	101·01	101·34	101·56	101·75	101·69					
2·87	2·96	1·22	0·74	0·41	0·19	0·00	0·06					
·00069	·00071	·00029	·00018	·00010	·00004	·0000	·0000					

$\frac{q}{k}=\frac{\cdot 0002402}{\cdot 0002402}=1.$

2301·3	2261·3	2208·8	2146·1	2071·2	2028·9	1996·7	1971·6	39818·3	2104·1			
88·51	86·97	84·95	82·54	79·66	78·03	76·79	75·83	1537·07	80·93	−0·93		
15·64	14·10	12·08	9·67	6·79	5·16	3·92	2·96					

made during the Month of December, 1847.

Zero from the 16th to the 31st, 113·24. Thermometer 80°.

3162·7	3128·9	3070·3	3021·5	2958·6	2898·9	2875·2	2839·6	55941·3	2944·2			
121·64	120·34	118·09	116·21	113·79	111·50	110·58	109·22	2151·59	113·24	−1·10	112·14	+ ·000264
17·46	15·09	12·09	9·87	6·73	4·46	3·36	2·36					
104·18	105·25	106·00	106·34	107·06	107·04	107·22	106·86					
3·46	2·41	1·64	1·30	0·58	0·60	0·42	0·78					
·00085	·00058	·00039	·00031	·00014	·00014	·00010	·00019					

$\frac{q}{k}=\frac{\cdot 0002402}{\cdot 0002402}=1.$

2353·0	2291·5	2213·5	2155·7	2074·1	2015·1	1986·5	1960·3	40061·3	2108·4			
90·50	88·13	85·13	82·91	79·77	77·50	76·40	75·40	1540·80	81·10	−1·10		
17·46	15·09	12·09	9·87	6·73	4·46	3·36	2·36					

TABLE B.

Observatory at Padang.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.

k=·00015987 × cot 60°=·0002402.
q =·0002402. Bifilar Magnetometer.

Sums	1667·1	1668·8	1665·0	1656·4	1659·9	1693·8	1726·2	1751·1	1780·8	1808·1	1849·4
Means of 13 days ...	128·24	128·37	128·08	127·42	127·68	130·29	132·78	134·70	136·98	139·08	142·26
Temp. corrections ...	0·55	0·33	0·08	0·00	0·81	4·51	9·14	12·36	14·66	16·25	18·22
Corrected means ...	127·69	128·04	128·00	127·42	126·87	125·78	123·64	122·34	122·32	122·83	124·04
Oscillations & diffs. .	2·35	2·00	2·04	2·62	3·17	4·26	6·40	7·70	7·72	7·21	6·00
$\frac{\delta X}{X}$	·00056	·00048	·00049	·00063	·00076	·00102	·00154	·00185	·00185	·00173	·00144

Thermometer of Bifilar.

Sums	957·8	955·0	951·7	950·7	961·2	1009·3	1069·5	1111·4	1141·3	1162·0	1187·5
Means of 13 days ...	73·68	73·46	73·21	73·13	73·94	77·64	82·27	85·49	87·79	89·38	91·35
Differences & corrs. .	0·55	0·33	0·08	0·00	0·81	4·51	9·14	12·36	14·66	16·25	18·22

Observatory at Bencoolen.—Hourly observations

k=·000415987 × cot 60°=·0002402.
q =·0002402. Bifilar Magnetometer.

Sums	395·8	394·8	394·4	393·7	232·2	403·8	410·7	417·8	422·3	428·1	435·6
Means of 5 days ...	79·16	78·96	78·88	78·74	77·40	80·76	82·14	83·56	84·46	85·62	87·12
Temp. corrections ...	−0·42	−0·22	−0·04	0·00	−2·03	−5·10	−8·28	−11·18	−12·34	−13·28	−12·78
Corrected means ..	78·74	78·74	78·84	78·74	75·37	75·66	73·86	72·38	72·12	72·34	74·34
Oscillations & diffs. .	1·30	1·30	1·20	1·30	4·67	4·38	6·18	7·66	7·92	7·70	5·70
$\frac{\delta X}{X}$	·00031	·00031	·00029	·00031	·00112	·00105	·00148	·00183	·00190	·00185	·00137

Thermometer of Bifilar.

Sums	367·3	366·3	365·4	365·2	225·2	390·7	406·6	421·1	426·9	431·6	429·1
Means of 5 days ...	73·46	73·26	73·08	73·04	75·07	78·14	81·32	84·22	85·38	86·32	85·82
Differences & corrs. .	−0·42	−0·22	−0·04	0·00	−2·03	−5·10	−8·28	−11·18	−12·34	−13·28	−12·78

TABLE B.

made during the Month of January, 1848.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
X=7·9456. Zero from the 16th to the 31st. Scale Divisions 134·80. Thermometer 80°.												
1861·6	1858·8	1841·4	1817·5	1776·0	1751·2	1736·1	1727·7	33296·9	1752·6			
143·20	142·98	141·65	139·81	136·62	134·71	133·55	132·90	2561·30	134·80	−1·21	133·59	+·000291
17·47	15·23	13·26	10·94	7·76	5·35	3·75	2·86					
125·73	127·75	128·39	128·87	128·86	129·36	129·80	130·04					
4·31	2·29	1·65	1·17	1·18	0·68	0·24	0·00					
·00103	·00055	·00040	·00028	·00028	·00016	·00006	0·00					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
1177·8	1148·7	1123·1	1092·9	1051·6	1020·2	999·4	987·9	20059·0	1055·9			
90·60	88·36	86·39	84·07	80·89	78·48	76·88	75·99	1543·00	81·21			
17·47	15·23	13·26	10·94	7·76	5·35	3·75	2·86					

made during the Months of August and September, 1847.

Zero from the 31st to the 4th. Scale Divisions 83·08. Thermometer 80°.												
429·8	431·0	436·7	431·0	422·8	417·8	414·9	413·3	7726·5	415·7			
85·96	86·20	87·34	86·20	84·56	83·56	82·98	82·66	1576·26	83·08	+0·54	83·62	−·000130
−10·82	−9·16	−9·66	−8·28	−6·06	−4·66	−3·32	−2·62					
75·14	77·04	77·68	77·92	78·50	78·90	79·66	80·04					
4·90	3·00	2·36	2·12	1·54	1·14	0·38	0·00					
·00118	·00072	·00057	·00075	·00037	·00027	·00009	0·00					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
419·3	411·0	413·5	406·6	395·5	388·5	381·8	378·3	7389·9	397·3			
83·86	82·20	82·70	81·32	79·10	77·70	76·36	75·66	1508·01	79·46	+0·54		
−10·82	−9·16	−9·66	−8·28	−6·06	−4·66	−3·32	−2·62					

TABLE B.

Observatory at Batavia.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.

$k = \cdot000415987 \times \cot 60° = \cdot0002402.$
$q = \cdot0002402.$
Bifilar Magnetometer.

Sums	1544·3	1625·1	1612·0	1611·9	1605·8	1598·7	1587·5	1596·4	1619·1	1635·2	1658·3	1688·8	1713·3
Means of 19 days ...	85·79	85·53	84·84	84·84	84·52	84·14	83·55	84·02	85·22	86·06	87·28	88·88	90·17
Temp. corrections ...	−1·89	−1·45	−1·10	−0·69	−0·51	−0·35	0·00	−1·43	−3·90	−6·23	−8·29	−9·94	−10·83
Corrected means ...	83·90	84·08	83·74	84·15	84·01	83·79	83·55	82·59	81·32	79·83	78·99	78·94	79·34
Oscillations & diffs.	0·25	0·07	0·41	0·00	0·14	0·36	0·60	1·56	2·83	4·32	5·16	5·21	4·81
$\frac{\delta X}{X}$	·00006	·00002	·00009	0·00	·00003	·00009	·00014	·00037	·00068	·00104	·00124	·00125	·00115

Thermometer of Bifilar.

Sums	1392·9	1461·9	1455·2	1447·4	1444·0	1440·9	1434·4	1461·4	1508·5	1552·7	1591·9	1623·2	1640·0
Means of 19 days ...	77·38	76·94	76·59	76·18	76·00	75·84	75·49	76·92	79·39	81·72	83·78	85·43	86·32
Differences & corrs...	−1·89	−1·45	−1·10	−0·69	−0·51	−0·35	0·00	−1·43	−3·90	−6·23	−8·29	−9·94	−10·83

Observatory at Batavia.—Hourly observations

$k = \cdot000415987 \times \cot 60° = \cdot0002402.$
$q = \cdot0002402.$
Bifilar Magnetometer.

Sums	2159·8	2152·7	2145·5	2227·6	2218·2	2210·0	2202·2	2202·1	1636·8	1490·1	1520·7	1536·3	2350·0
Means of 25 days ...	86·39	86·11	85·82	85·68	85·32	85·00	84·70	84·70	86·15	87·65	89·45	90·37	90·38
Temp. corrections ...	−1·49	−1·18	−0·87	−0·57	−0·28	−0·13	0·00	−0·97	−3·43	−6·05	−8·39	−9·52	−9·19
Corrected means ...	84·90	84·93	84·95	85·11	85·04	84·87	84·70	83·73	82·72	81·60	81·06	80·85	81·19
Oscillations & diffs.	0·88	0·85	0·83	0·67	0·74	0·91	1·08	2·05	3·06	4·18	4·72	4·93	4·59
$\frac{\delta X}{X}$	·00021	·00020	·00020	·00016	·00018	·00022	·00026	·00049	·00073	·00100	·00113	·00120	·00110

Thermometer of Bifilar.

Sums	1927·1	1919·3	1911·6	1980·2	1972·7	1968·7	1965·3	1990·5	1501·4	1387·9	1427·7	1446·9	2204·4
Mean of 25 days ...	77·08	76·77	76·46	76·16	75·87	75·72	75·59	76·56	79·02	81·64	83·98	85·11	84·78
Differences & corrs...	−1·49	−1·18	−0·87	−0·57	−0·28	−0·13	0·00	−0·97	−3·43	−6·05	−8·39	−9·52	−9·19

Table B.

made during the Month of November, 1846.

Zero from the 9th to the 30th. Scale Divisions 87·33. Thermometer 80°.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Temp. Corrs	Corr. Means.	$\frac{\delta X}{X}$.
1729·1	1739·1	1741·1	1736·1	1721·8	1696·6	1674·3	1658·0	1650·7	1647·8	1642·3	39733·3	1659·0			
91·00	91·53	91·64	91·37	90·62	89·29	88·12	87·26	86·88	86·73	86·44	2095·72	87·33	−0·32	87·01	+ ·000077
−10·65	−10·59	−9·69	−8·63	−7·19	−5·54	−4·57	−3·81	−3·19	−2·81	−2·46					
80·35	80·94	81·95	82·74	83·43	83·75	83·55	83·45	83·69	83·92	83·98					
3·80	3·21	2·20	1·41	0·72	0·40	0·60	0·70	0·46	0·23	0·17					
·00091	·00077	·00053	·00034	·00017	·00009	·00014	·00017	·00011	·00005	·00004					

$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$

1636·7	1635·5	1618·5	1598·2	1570·9	1539·6	1521·2	1506·7	1495·0	1487·7	1481·1	36545·5	1525·8			
86·14	86·08	85·18	84·12	82·68	81·03	80·06	79·30	78·68	78·30	77·95	1927·50	80·32	−0·32		
−10·65	−10·59	−9·69	−8·63	−7·19	−5·54	−4·57	−3·81	−3·19	−2·81	−2·46					

made during the Month of December, 1846.

Zero from the 1st to the 31st. Scale Divisions 88·44. Thermometer 80°.

2387·3	2409·7	2420·5	2415·8	2384·5	2254·8	2237·1	1690·4	1326·8	1316·0	1308·2	48203·1	2299·2			
91·82	92·68	93·10	92·92	91·71	90·19	89·48	88·97	88·45	87·73	87·21	2121·98	88·44	+0·12	88·56	− ·000030
−9·51	−9·41	−8·88	−8·18	−6·49	−4·76	−3·88	−3·19	−2·74	−2·40	−1·87					
82·31	83·27	84·22	84·74	85·22	85·43	85·60	85·78	85·71	85·33	85·34					
3·47	2·51	1·56	1·04	0·56	0·35	0·18	0·00	0·07	0·45	0·44					
·00083	·00060	·00037	·00025	·00013	·00008	·00004	0·00	·00002	·00011	·00011					

$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$

2212·7	2209·9	2196·1	2178·1	2134·1	2008·8	1986·7	1496·8	1174·9	1169·9	1161·9	43533·6	2075·8			
85·10	85·00	84·47	83·77	82·08	80·35	79·47	78·78	78·33	77·99	77·46	1917·54	79·88	+0·12		
−9·51	−9·41	−8·88	−8·18	−6·49	−4·76	−3·88	−3·19	−2·74	−2·40	−1·87					

TABLE B.

Observatory at Batavia.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
$k = \cdot000415987 \times \cot 60^\circ = \cdot0002402.$ $q = \cdot0002402.$ Bifilar Magnetometer.													
Sums	1657·2	1651·3	1637·4	2254·8	2242·8	2230·7	2221·1	2218·7	2237·1	2251·1	2259·7	2278·2	2316·3
Means of 25 days ...	92·07	91·74	90·97	90·19	89·71	89·23	88·84	88·75	89·48	90·04	90·39	91·13	92·65
Temp. corrections ...	−2·71	−2·19	−1·59	−0·93	−0·63	−0·30	0·00	−0·82	−1·68	−4·82	−6·53	−7·86	−8·38
Corrected means ...	89·36	89·55	89·38	89·26	89·08	88·93	88·84	87·93	87·80	85·22	83·86	83·27	84·27
Oscillations & diffs. .	0·45	0·26	0·43	0·55	0·73	0·88	0·97	1·88	2·01	4·59	5·95	6·54	5·54
$\frac{\delta X}{X}$	·00011	·00006	·00010	·00013	·00017	·00021	·00023	·00045	·00048	·00088	·00143	·00157	·00133
Thermometer of Bifilar.													
Sums	1398·8	1389·4	1378·6	1898·3	1890·7	1882·5	1874·9	1895·5	1942·0	1995·4	2038·3	2071·5	2097·1
Means of 25 days ...	77·71	77·19	76·59	75·93	75·63	75·30	75·00	75·82	77·68	79·82	81·53	82·86	83·88
Differences & corrs. .	−2·71	−2·19	−1·59	0·93	0·63	0·30	0·00	0·82	1·68	4·82	6·53	7·86	8·38

Observatory at Batavia.—Hourly observations

$k = \cdot000415987 \times \cot 60^\circ = \cdot0002402.$ $q = \cdot0002402.$ Bifilar Magnetometer.													
Sums	1539·0	1535·8	1531·2	2297·9	2295·9	2287·6	2278·3	2274·9	2276·1	2291·4	2306·2	2323·4	2355·2
Means of 24 days ...	96·19	95·99	95·70	95·75	95·66	95·32	94·93	94·79	94·84	95·48	96·09	96·81	98·13
Temp. corrections ...	−1·33	−1·15	−0·89	−0·53	−0·34	−0·19	0·00	−0·36	−1·66	−3·81	−5·48	−6·84	−7·90
Corrected means ...	94·86	94·84	94·81	95·22	95·32	95·13	94·93	94·43	93·18	91·67	90·61	89·97	90·23
Oscillations & diffs.	1·38	1·40	1·43	1·02	0·92	1·11	1·31	1·81	3·06	4·57	5·63	6·27	6·01
$\frac{\delta X}{X}$	·00033	·00034	·00034	·00024	·00022	·00027	·00031	·00043	·00073	·00110	·00135	·00151	·00144
Thermometer of Bifilar.													
Sums	1235·5	1232·7	1228·5	1834·0	1829·4	1826·0	1821·4	1830·0	1861·2	1912·8	1952·8	1985·5	2011·0
Means of 24 days ...	77·22	77·04	76·78	76·42	76·23	76·08	75·89	76·25	77·55	79·70	81·37	82·73	83·79
Differences & corrs. .	−1·33	−1·15	−0·89	−0·53	−0·34	−0·19	0·00	−0·36	−1·66	−3·81	−5·48	−6·84	−7·90

TABLE B.

made during the Month of January, 1847.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
Zero from the 1st to the 30th. Scale Divisions 92·64. Thermometer 80°.															
2359·4	2386·6	2419·9	2436·7	2432·0	2409·9	2378·8	1892·5	1696·5	1686·4	1675·3	51230·4	2313·9			+ ·000010
94·38	95·46	96·80	97·47	97·28	96·40	95·15	94·63	94·25	93·69	93·07	2223·77	92·64	−0·04	92·60	
−9·81	−9·97	−9·92	−9·48	−8·71	−7·20	−5·63	−5·04	−4·63	−3·88	−3·37					
84·57	85·49	86·88	87·99	88·57	89·20	89·52	89·59	89·62	89·81	89·70					
5·24	4·32	2·93	1·82	1·24	0·61	0·29	0·22	0·19	0·00	0·11					
·00126	·00104	·00070	·00044	·00030	·00015	·00007	·00005	·00004	0·00	·00026					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$															
2120·3	2124·2	2123·1	2112·1	2092·7	2054·9	2015·8	1600·9	1433·3	1419·8	1410·7	44260·8	1998·3			
84·81	84·97	84·92	84·48	83·71	82·20	80·63	80·04	79·63	78·88	78·37	1917·58	80·04	−0·04		
9·81	9·97	9·92	9·48	8·71	7·20	5·63	5·04	4·63	3·88	3·37					

made during the Month of February, 1847.

Zero from the 1st to the 28th. Scale Divisions 97·70. Thermometer 80°.															
2385·1	2417·1	2431·4	2438·0	2424·1	2410·5	2395·0	2384·0	2273·8	1364·8	1360·8	51877·5	2348·0			− ·000074
99·38	100·71	101·31	101·58	101·00	100·44	99·79	99·33	98·86	97·49	97·20	2342·77	97·70	+0·31	98·01	
−8·34	−8·52	−8·09	−6·97	−5·72	−4·73	−3·90	−3·09	−2·83	−2·56	−2·07					
91·04	92·19	93·22	94·61	95·28	95·71	95·89	96·24	96·03	94·93	95·13					
5·20	4·05	3·02	1·63	0·96	0·53	0·35	0·00	0·21	1·31	1·11					
·00125	·00097	·00073	·00039	·00023	·00013	·00008	0·00	·00005	·00031	·00027					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$															
2021·5	2025·9	2015·6	1988·7	1958·6	1934·9	1915·0	1895·5	1810·5	1098·3	1091·4	42316·7	1913·7			
84·23	84·41	83·98	82·86	81·61	80·62	79·79	78·98	78·72	78·45	77·96	1908·66	79·69	+0·31		
−8·34	−8·52	−8·09	−6·97	−5·72	−4·73	−3·90	−3·09	−2·83	−2·56	−2·07					

Table B.

Observatory at Batavia.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
k=000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.											
Sums	2704·4	2688·8	2674·3	2663·6	2663·3	2665·2	2686·0	2706·6	2725·7	2739·0	2765·7
Means of 27 days ...	100·16	99·59	99·05	98·65	98·64	98·71	99·48	100·24	100·95	101·44	102·43
Temp. corrections ...	−1·00	−0·68	−0·23	−0·00	−0·58	−2·43	−4·67	−6·29	−7·55	−8·38	−8·69
Corrected means ...	99·16	98·91	98·82	98·65	98·06	96·28	94·81	93·95	93·40	93·06	93·74
Oscillations & diffs. .	0·00	0·25	0·34	0·51	1·10	2·88	4·35	5·21	5·76	6·10	5·42
$\frac{\delta X}{X}$	0·00	·00006	·00008	·00012	·00026	·00069	·00104	·00125	·00138	·00146	·00130
Thermometer of Bifilar.											
Sums	2092·9	2084·2	2072·0	2065·9	2081·3	2131·4	2191·9	2235·7	2269·6	2292·1	2300·4
Means of 27 days ...	77·51	77·19	76·74	76·51	77·09	78·94	81·18	82·80	84·06	84·89	85·20
Differences & corrs. .	−1·00	−0·68	−0·23	0·00	−0·58	−2·43	−4·67	−6·29	−7·55	−8·38	8·69

Observatory at Batavia.—Hourly observations

k=·00041598 × cot 60°=·0002402. q= =·0002402. Bifilar Magnetometer.											
Sums	2734·8	2718·2	2703·7	2680·4	2683·6	2704·3	2626·1	2751·2	2764·7	2804·5	2841·9
Means of 26 days ...	105·18	104·55	103·99	103·09	103·22	104·01	105·04	105·82	106·33	107·87	109·30
Temp. corrections ...	−1·37	−0·72	−0·22	0·00	−1·42	−3·59	−5·39	−8·33	−9·48	−10·20	−10·14
Corrected means ...	103·81	103·83	103·77	103·09	101·80	100·42	99·65	97·49	96·85	97·67	99·16
Oscillations & diffs. .	0·56	0·54	0·60	1·28	2·57	3·95	4·72	6·88	7·52	6·70	5·21
$\frac{\delta X}{X}$	·00013	·00013	·00014	·00031	·00062	·00095	·00113	·00165	·00181	·00161	·00125
Thermometer of Bifilar.											
Sums	2000·8	1983·8	1970·8	1965·0	2001·9	2058·4	2049·2	2181·7	2211·5	2230·2	2228·7
Means of 26 days ...	76·95	76·30	75·80	75·58	77·00	79·17	81·97	83·91	85·06	85·78	85·72
Differences & corrs. .	−1·37	−0·72	−0·22	0·00	−1·42	−3·59	−5·39	−8·33	−9·48	−10·20	−10·14

TABLE B.

made during the Month of March, 1847.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
Zero from the 1st to the 31st. Scale Divisions 101·77. Thermometer 80°.												
2811·5	2854·0	2866·6	2855·2	2816·7	2795·9	2780·5	2640·7	52103·7	2742·4			
104·13	105·70	106·17	105·75	104·32	103·55	102·98	101·57	1933·51	101·77	−1·31	100·46	+ ·000315
−8·93	−8·90	−8·35	−7·34	−5·56	−4·64	−3·87	−2·95					
95·20	96·72	97·82	98·41	98·76	98·91	99·11	98·62					
3·96	2·44	1·34	0·75	0·40	0·25	0·05	0·54					
·00095	·00059	·00032	·00018	·00010	·00006	·00001	·00013					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
2306·8	2308·3	2291·3	2264·0	2215·9	2191·1	2170·3	2065·9	41631·0	2195·6			
85·44	85·49	84·86	83·85	82·07	81·15	80·38	79·46	1544·81	81·31	−1·31		
−8·93	−8·98	−8·35	−7·34	−5·56	−4·64	−3·87	−2·95					

made during the Month of April, 1847.

Zero from the 1st to the 30th. Scale Divisions 107·40. Thermometer 80°.												
2888·2	2814·2	2930·7	2906·4	2212·4	2192·0	2164·1	2142·9	50264·3	2790·4			
111·08	112·57	112·72	111·78	110·62	109·60	108·21	107·15	2042·13	107·40	−1·25	106·15	·000300
−9·96	−9·48	−8·90	−7·70	−6·25	−5·27	−4·22	−3·52					
101·12	103·09	103·82	104·08	104·37	104·33	103·99	103·63					
3·25	1·28	0·55	0·29	0·00	0·04	0·38	0·74					
·00078	·00031	·00013	·00007	·00024	·00001	·00009	·00018					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
2224·0	2126·4	2196·5	2165·3	1636·5	1616·9	1596·0	1581·9	38025·5	2112·9			
85·54	85·06	84·48	83·28	81·83	80·85	79·80	79·10	1543·18	81·25	−1·25		
−9·96	−9·48	−8·90	−7·70	−6·25	−5·27	−4·22	−3·52					

TABLE B.

Observatory at Batavia.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1:
k=·000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.											
Sums	2849·3	2831·1	2811·1	2792·1	2802·8	2840·4	2460·0	2926·6	2947·9	2987·0	3012·5
Means of 26 days	109·59	108·89	108·12	107·39	107·80	109·25	111·82	112·56	113·38	114·88	115·87
Temp. corrections	−1·47	−0·95	0·40	0·00	−1·43	−4·58	−8·43	−9·70	−11·12	−12·36	−11·96
Corrected means	108·12	107·94	107·72	107·39	106·37	104·67	103·39	102·86	102·26	102·52	103·91
Oscillations & diffs.	−0·75	0·93	1·15	1·48	2·50	4·20	5·48	6·01	6·61	6·35	4·96
$\frac{\delta X}{X}$	·00018	·00022	·00028	·00035	·00060	·00101	·00132	·00144	·00159	·00152	·00119
Thermometer of Bifilar.											
Sums	1976·6	1963·0	1948·6	1938·3	1975·6	2057·5	1825·5	2190·6	2227·3	2259·7	2249·2
Means of 26 days	76·02	75·50	74·95	74·55	75·98	79·13	82·98	84·25	85·67	86·91	86·51
Differences & corrs.	−1·47	−0·95	−0·40	0·00	−1·43	−4·58	−8·43	−9·70	−11·12	−12·36	−11·96

Observatory at Batavia.—Hourly observations

k=·000415987 × cot 60°=·0002402. q =·0002402. Bifilar Magnetometer.											
Sums	2953·1	2928·1	2897·6	2762·3	2785·6	2815·3	2418·3	2909·2	3059·5	3099·8	3120·4
Means of 26 days	113·58	112·62	111·45	110·49	111·42	112·61	115·16	116·37	117·67	119·22	120·02
Temp. corrections	−1·30	−0·68	−0·20	0·00	−1·82	−4·50	−8·37	−10·42	−11·89	−12·87	−12·90
Corrected means	112·28	111·94	111·25	110·49	109·60	108·11	106·79	105·95	105·78	106·35	107·12
Oscillations & diffs.	0·00	0·34	1·03	1·79	2·68	4·17	5·49	6·33	6·50	5·93	5·16
$\frac{\delta X}{X}$	·00000	·00008	·00025	00043	·00064	·00100	·00132	·00152	·00156	·00142	·00124
Thermometer of Bifilar.											
Sums	1957·8	1941·8	1929·2	1850·0	1895·5	1962·6	1729·7	2110·5	2233·1	2258·7	2259·5
Means of 26 days	75·30	74·68	74·20	74·00	75·82	78·50	82·37	84·42	85·89	86·87	86·90
Differences & corrs.	−1·30	−0·68	−0·20	0·00	−1·82	−4·50	−8·37	−10·42	−11·89	−12·87	−12·90

Table B.

made during the Month of May, 1847.

	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
Zero from the 1st to the 31st. Scale Divisions 112·95. Thermometer 80°.													
	3031·2	2599·6	3076·7	3059·1	2898·7	2747·9	2727·1	2701·4	54102·5	2935·8			
	116·58	118·16	118·33	117·66	115·95	114·50	113·63	112·56	2146·92	112·95	−1·16	111·79	+ ·000279
	−11·05	−11·06	−10·41	−9·01	−7·08	−5·93	−5·05	−4·30					
	105·53	107·10	107·92	108·65	108·87	108·57	108·58	108·26					
	3·34	1·77	0·95	0·22	0·00	0·30	0·29	0·61					
	·00080	·00042	·00023	·00005	0·00	·00007	·00007	·00015					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$													
	2225·5	1883·4	2208·9	2172·5	2040·8	1931·6	1910·4	1892·4	38877·4	2109·7			
	85·60	85·61	84·96	83·56	81·63	80·48	79·60	78·85	1542·74	81·16	−1·16		
	−11·05	−11·06	−10·41	−9·01	−7·08	−5·93	−5·05	−4·30					

made during the Month of June, 1847.

Zero from the 1st to the 30th. Scale Divisions 116·43. Thermometer 80°.													
	3030·1	2558·3	3028·4	2886·5	2729·9	2468·3	2446·4	2428·1	53325·2	3027·1			
	121·20	121·82	121·14	120·27	118·69	117·54	116·50	115·62	2213·39	116·43	−1·03	115·40	+ ·000247
	−12·59	−12·16	−10·78	−9·41	−7·17	−6·24	−5·46	−5·41					
	108·61	109·66	110·36	110·86	111·52	111·30	111·04	110·21					
	3·67	2·62	1·92	1·42	1·66	0·98	1·14	2·07					
	·00088	·00063	·00046	·00034	·00040	·00023	·00027	·00050					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$													
	2164·7	1809·4	2119·5	2001·8	1866·8	1685·0	1668·7	1667·7	37112·0	2104·8			
	86·59	86·16	84·78	83·41	81·17	80·24	79·46	79·41	1540·17	81·03	−1·03		
	−12·59	−12·16	−10·78	−9·41	−7·17	−6·24	−5·46	−5·41					

TABLE B.

Observatory at Cocos Island.—Hourly observations made

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.	1.
$k=\cdot000415987\times\cot 60^\circ=\cdot0002402.$ $q \qquad =\cdot0002402.$ Bifilar Magnetometer.											
Sums	2152·6	2137·9	2130·3	2121·6	2091·7	2092·3	2103·7	2111·6	2124·5	2126·3	2154·3
Means of 27 days	79·73	79·18	78·90	78·58	77·47	77·49	77·91	78·21	78·69	78·75	79·79
Temp. corrections	−0·32	−0·16	−0·11	0·00	−0·42	−1·61	−3·31	−4·35	−5·62	−5·99	−5·93
Corrected means	79·41	79·02	78·79	78·58	77·05	75·88	74·60	73·86	73·07	72·76	73·86
Oscillations & diffs.	0·98	1·37	1·60	1·81	3·34	4·51	5·79	6·53	7·32	7·63	6·53
$\frac{\delta X}{X}$	·00023	·00033	·00038	·00043	·00080	·00108	·00139	·00157	·00176	·00183	·00157
Thermometer of Bifilar.											
Sums	2079·6	2075·2	2073·9	2070·9	2082·3	2114·3	2160·2	2188·4	2222·6	2232·7	2231·1
Means of 27 days	77·02	76·86	76·81	76·70	77·12	78·31	80·01	81·05	82·32	82·69	82·63
Differences & corrs.	−0·32	−0·16	−0·11	0·00	−0·42	−1·61	−3·31	−4·35	−5·62	−5·99	−5·93

TABLE B.

during the Months of August and September, 1848.

2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Temp. Corrs.	Corrected Means.	$\frac{\delta X}{X}$.
Zero from the 28th of August to the 27th of September. Scale Divisions 79·76. Thermometer 80°.												
2179·2	2193·6	2204·5	2193·5	2183·1	2183·2	2192·5	2190·2	41872·4	2151·6			
80·71	81·24	81·65	81·24	80·86	80·86	81·20	81·12	1513·58	79·76	+0·94	80·70	−·000226
−5·10	−4·14	−3·28	−2·06	−1·20	−0·96	−0·83	−0·73					
75·61	77·10	78·37	79·18	79·66	79·90	80·37	80·39					
4·78	3·29	2·02	1·21	0·73	0·49	0·02	0·00					
·00115	·00079	·00048	·00029	·00017	·00012	·00001	0·00					
$\frac{q}{k}=\frac{\cdot0002402}{\cdot0002402}=1.$												
2208·5	2182·6	2159·4	2126·6	2103·4	2096·7	2093·3	2090·7	41513·7	2135·1			
81·80	20·84	79·98	78·76	77·90	77·66	77·53	77·43	1503·42	79·07			
−5·10	−4·14	−3·28	−2·06	−1·20	−0·96	−0·83	−0·73					

Table C.

Variation of the Dry Thermometer at

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Moulmein	......	......	......	0·5	0·2	0·0	0·1	2·9	10·5	14·2	18·8
Madras	......	......	......	1·1	0·8	0·3	0·0	1·4	4·5	7·7	10·4
Nicobar	......	......	......	0·0	0·6	0·8	0·9	2·0	6·6	9·0	12·8
Sambooanga	......	......	......	0·2	0·1	0·3	0·0	4·7	9·6	10·8	11·2
Penang	......	......	......	1·5	1·0	0·0	0·2	1·1	3·3	7·5	11·1
Pulo Dinding	......	......	......	1·4	1·0	0·3	0·0	0·5	5·8	11·1	18·4
Sarawak	1·6	1·3	1·0	0·8	0·6	0·4	0·0	0·3	1·7	4·0	6·2
Keemah	......	......	......	1·0	0·7	0·4	0·0	2·7	9·4	12·3	15·6
Pulo Peesang	......	......	......	......	0·8	0·0	0·2	1·0	2·0	5·0	9·2
Singapore	......	......	......	1·3	1·1	0·9	0·3	0·0	0·8	2·0	5·5
Carimon	......	......	......	......	......	0·6	0·0	2·4	5·5	8·0	9·8
Padang	......	......	......	0·5	0·2	0·0	0·0	1·5	5·9	10·0	12·2
Bencoolen	......	......	......	1·4	1·2	0·0	1·0	4·0	7·1	9·7	12·3
Batavia, Winter	1·8	1·5	1·1	0·7	0·4	0·2	0·0	1·2	3·4	5·8	7·6
Batavia, Spring	......	......	......	1·4	0·9	0·3	0·0	1·2	4·1	7·6	9·6
Cocos	......	......	......	0·4	0·3	0·3	0·0	0·4	1·7	3·5	4·8

Variation of the Dry Thermometer at

June ....1846...	1·5	1·1	0·8	0·6	0·4	0·4	0·0	0·5	2·0	4·3	6·7
July	1·8	1·5	1·2	0·9	0·7	0·6	0·0	0·3	1·6	3·8	5·7
August	1·6	1·3	1·0	0·8	0·6	0·3	0·0	0·2	1·5	4·0	6·1
Sums	4·9	3·9	3·0	2·3	1·7	1·3	0·0	1·0	5·1	12·1	18·5
Means and Variation	1·6	1·3	1·0	0·8	0·6	0·4	0·0	0·3	1·7	4·0	6·2

Variation of the Dry Thermometer at

October ....1847...	......	......	......	0·5	0·3	0·1	0·0	2·0	6·5	10·5	12·6
November	......	......	......	0·5	0·2	0·0	0·0	1·9	6·5	10·1	12·1
December	......	......	......	0·6	0·3	0·0	0·0	1·2	5·5	9·9	12·7
January ....1848...	......	......	......	0·5	0·2	0·0	0·0	0·9	5·2	9·6	11·6
Sums	......	......	......	2·1	1·0	0·1	0·0	6·0	23·7	40·1	49·0
Means and Variation	......	......	......	0·5	0·2	0·0	0·0	1·5	5·9	10·0	12·2

Variation of the Dry Thermometer at

November ......1848...	......	......	......	1·1	0·9	0·8	0·5	0·0	0·6	1·6	2·4
December	......	......	......	1·5	1·3	1·0	0·2	0·0	1·1	2·5	3·1
Sums	......	......	......	2·7	2·2	1·8	0·7	0·0	1·7	4·1	5·5
Means and Variation	......	......	......	1·3	1·1	0·9	0·3	0·0	0·8	2·0	2·7

Table C.

various Stations in the Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
21·9	24·3	23·7	24·0	20·4	18·8	15·7	9·8	6·6	4·7	4·0	......	......	11·7
12·7	14·5	15·5	15·1	13·7	12·2	9·6	7·2	5·4	4·5	3·9	......	......	7·4
13·5	13·7	14·6	12·5	12·2	11·6	10·3	7·4	5·5	4·6	3·4	......	......	7·5
10·0	12·4	13·3	14·0	13·5	12·2	10·1	7·8	7·1	5·5	4·6	......	......	7·7
13·1	12·0	11·4	10·5	10·7	9·9	7·9	5·8	4·7	4·2	3·4	......	......	6·3
22·2	20·5	21·8	18·5	16·4	13·1	9·1	5·4	4·3	4·0	3·3	......	......	9·3
8·0	9·6	10·2	10·4	9·5	8·3	7·1	5·1	3·6	2·9	2·6	2·2	1·9	4·1
17·1	18·6	14·1	12·6	11·6	10·7	8·5	6·8	5·6	4·7	4·0	......	......	8·1
12·0	13·5	13·7	9·7	7·3	6·7	4·2	3·1	2·9	3·0	2·1	......	......	5·7
3·4	3·9	3·8	3·4	3·2	3·0	2·6	2·4	2·2	2·0	1·6	......	......	2·2
12·8	12·2	13·0	13·3	11·1	10·0	8·0	4·7	3·7	2·8	......	......	......	7·4
14·0	15·5	16·0	15·1	13·3	11·1	8·7	6·1	4·6	3·4	2·6	......	......	7·4
12·9	13·6	13·0	11·3	10·0	10·5	8·7	6·2	5·1	4·3	3·6	......	......	7·3
8·9	9·6	9·8	10·0	9·5	8·6	7·0	5·3	4·4	3·7	2·8	2·9	2·3	4·6
10·9	11·8	11·8	11·3	11·0	10·2	8·6	6·6	5·5	4·7	4·0	......	......	6·4
6·4	6·7	5·9	5·0	3·8	2·8	1·8	1·2	1·0	1·1	0·9	......	......	2·5

Sarawak in Borneo, Eastern Archipelago.

8·5	9·9	10·4	10·2	9·2	8·3	7·0	4·7	3·7	3·0	2·5	2·1	1·8	
7·6	9·1	9·3	9·8	8·7	8·3	7·3	5·4	3·6	3·0	2·7	2·3	2·0	
8·0	9·7	11·0	11·1	10·5	8·2	7·1	5·3	3·5	2·8	2·5	2·2	1·9	
24·1	28·7	30·7	31·1	28·4	24·8	21·4	15·4	10·8	8·8	7·7	6·6	5·7	
8·0	9·6	10·2	10·4	9·5	8·3	7·1	5·1	3·6	2·9	2·6	2·2	1·9	4·1

Padang, Sumatra, Eastern Archipelago.

14·0	14·6	14·3	14·1	12·4	10·4	8·1	6·3	4·9	3·4	2·8	......	......	
13·8	15·3	15·2	14·0	12·3	10·7	8·5	6·2	4·9	3·9	3·0	......	......	
14·4	16·8	16·9	15·9	13·9	10·7	8·5	5·7	4·1	3·2	2·1	......	......	
13·9	15·4	17·6	16·3	14·5	12·5	9·9	6·2	4·7	3·2	2·4	......	......	
56·1	62·1	64·0	60·3	53·1	44·3	35·0	24·4	18·6	13·7	10·3	......	......	
14·0	15·5	16·0	15·1	13·3	11·1	8·7	6·1	4·6	3·4	2·6	......	......	7·4

Singapore, Eastern Archipelago.

3·2	3·5	3·5	3·4	3·0	2·7	2·4	2·3	2·1	1·8	1·4	......	......	2·0
3·7	4·3	4·2	3·5	3·5	3·4	2·8	2·5	2·4	2·2	1·9	......	......	2·4
6·9	7·8	7·7	6·9	6·5	6·1	5·2	4·8	4·5	4·0	3·3	......	......	4·4
3·4	3·9	3·8	3·4	3·2	3·0	2·6	2·4	2·2	2·0	1·6	......	......	2·2

TABLE C.

Variation of the Dry Thermometer at Batavia

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
November ...1846......	1·9	1·5	1·2	0·8	0·6	0·4	0·0	1·9	4·4	7·1	9·2
December	1·7	1·3	1·0	0·7	0·3	0·1	0·0	1·3	3·9	6·7	8·9
January ......1847......	2·5	2·0	1·4	0·9	0·5	0·2	0·0	1·1	3·3	5·2	6·7
February	1·3	1·1	0·7	0·5	0·4	0·2	0·0	0·5	1·9	4·1	5·6
Sums	7·4	5·9	4·3	2·9	1·8	0·9	0·0	4·8	13·5	23·1	30·4
Means and Variation...	1·8	1·5	1·1	0·7	0·4	0·2	0·0	1·2	3·4	5·8	7·6

Variation of the Dry Thermometer at Batavia

March ......1847......	......	......	......	1·2	0·7	0·2	0·0	0·7	2·7	5·1	6·9
April	......	......	......	1·7	1·0	0·4	0·0	1·3	3·9	6·9	9·1
May	......	......	......	1·5	1·0	0·4	0·0	1·4	5·0	9·2	10·7
June	......	......	......	1·4	0·9	0·4	0·0	1·4	4·8	9·3	11·7
Sums	......	......	......	5·8	3·6	1·4	0·0	4·8	16·4	30·5	38·4
Means and Variation...	......	......	......	1·4	0·9	0·3	0·0	1·2	4·1	7·6	9·6

Variation of the Wet Thermometer at

Moulmein	......	......	......	0·7	0·6	0·0	0·1	1·9	5·5	6·7	7·9
Madras	......	......	......	1·3	0·9	0·4	0·0	0·9	1·6	1·9	3·1
Nicobar	......	......	......	0·0	0·5	0·5	0·5	1·7	5·1	6·1	8·2
Sambooanga	......	......	......	0·0	0·0	0·4	0·0	3·1	6·1	7·5	7·2
Penang	......	......	......	1·3	1·0	0·3	0·2	0·0	2·6	5·5	7·8
Pulo Dinding	......	......	......	1·5	0·8	0·4	0·0	1·0	3·6	7·3	10·0
Sarawak..................	1·3	1·1	0·8	0·6	0·5	0·3	0·0	0·3	1·3	2·7	3·5
Keemah	......	......	......	1·1	0·9	0·6	0·0	2·6	6·0	8·1	9·9
Pulo Peesang	......	......	......	......	0·5	0·0	0·1	0·8	1·3	3·0	5·0
Singapore	......	......	......	0·9	0·8	0·7	0·2	0·0	0·4	1·0	1·3
Carimon..................	......	......	......	......	......	0·1	0·0	1·4	2·7	3·7	4·1
Padang	......	......	......	0·5	0·3	0·1	0·0	1·2	3·8	6·2	6·8
Bencoolen	......	......	......	0·5	0·2	0·0	0·0	2·2	3·8	5·0	5·9
Batavia, Winter.........	1·1	1·0	0·7	0·5	0·3	0·1	0·0	0·7	1·9	2·8	3·3
Batavia, Spring.........	......	......	......	0·9	0·6	0·2	0·0	0·9	2·3	3·7	4·2
Cocos......................	......	......	......	0·1	0·1	0·1	0·0	0·2	1·0	2·2	2·9

Variation of the Wet Thermometer at

June ....1846......	1·2	1·0	0·8	0·6	0·4	0·3	0·0	0·4	1·5	2·9	3·8
July	1·4	1·2	0·9	0·6	0·5	0·3	0·0	0·3	1·2	2·6	3·3
August	1·3	1·1	0·8	0·6	0·5	0·2	0·0	0·3	1·2	2·5	3·4
Sums	3·9	3·3	2·5	1·8	1·4	0·8	0·0	1·0	3·9	8·0	10·5
Means and Variation...	1·3	1·1	0·8	0·6	0·5	0·3	0·0	0·3	1·3	2·7	3·5

Table C.

in Java, Eastern Archipelago. Winter.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
10·6	11·6	11·1	11·3	10·2	9·2	7·3	5·0	4·5	3·8	1·3	2·9	2·5	5·1
10·0	9·5	9·5	9·5	9·4	8·1	6·3	4·6	3·7	3·0	2·6	2·3	1·7	4·4
8·0	9·2	10·2	10·4	10·5	10·0	8·8	7·0	5·7	5·0	4·5	3·8	3·2	5·2
7·0	8·2	8·6	8·9	8·1	7·0	5·7	4·5	3·8	3·1	2·8	2·5	1·9	3·9
35·6	38·5	39·4	40·1	38·2	34·3	28·1	21·1	17·7	14·9	11·2	11·5	9·3	18·6
8·9	9·6	9·8	10·0	9·5	8·6	7·0	5·3	4·4	3·7	2·8	2·9	2·3	4·6

in Java, Eastern Archipelago. Spring.

8·1	9·0	9·6	9·6	9·7	9·0	7·6	5·5	4·6	3·7	2·8	……	……	5·1
10·2	11·1	11·1	10·4	10·1	9·6	8·1	6·6	5·6	4·7	4·0	……	……	6·1
12·2	13·3	12·6	11·6	11·4	10·8	9·1	7·0	5·6	4·9	4·3	……	……	6·9
13·1	13·9	14·0	13·5	12·9	11·3	9·8	7·4	6·4	5·5	5·0	……	……	7·5
43·6	47·3	47·3	45·1	44·1	40·7	34·6	26·5	22·2	18·8	16·1	……	……	25·6
10·9	11·8	11·8	11·3	11·0	10·2	8·6	6·6	5·5	4·7	4·0	……	……	6·4

various stations in the Eastern Archipelago.

8·4	9·1	8 4	7·1	6·1	5·5	4·6	3·0	2·5	2·3	2·0	……	……	4·3
3·5	4·0	4·4	4·5	4·8	4·5	4·2	3·7	3·9	3·8	3·6	……	……	2·9
8·0	8·2	9·1	7·5	7·6	7·4	6·7	5·3	4·0	3·6	2·6	……	……	4·9
6·2	7·6	8·0	9·1	8·6	8·3	6·8	5·8	5·1	4·1	3·6	……	……	5·1
8·6	7·8	7·0	6·5	6·3	6·6	5·3	4·2	3·8	3·3	2·7	……	……	3·3
11·5	10·0	11·4	9·8	10·6	7·7	6·1	3·8	3·2	2·4	2·7	……	……	5·4
4·1	4·5	4·8	4·7	4·5	4·2	3·9	3·7	2·8	2·4	2·0	1·8	1·5	2·4
11·0	12·1	8·8	8·7	7·9	7·2	6·6	5·7	5·0	4·2	3·7	……	……	5·7
5·7	5·6	6·0	4·5	3·6	3·9	2·8	2·0	2·1	1·9	1·5	……	……	3·0
1·6	2·0	2·2	2·0	2·5	1·8	1·5	1·7	1·8	1·7	1·5	……	……	1·3
5·3	4·8	5·3	5·7	4·5	4·3	3·5	2·5	1·7	1·0	……	……	……	3·2
7·8	8·5	8·8	8·3	7·6	6·9	5·9	4·7	4·1	3·2	2·8	……	……	4·6
6·2	6·8	6·9	6·5	5·4	5·7	5·1	3·7	2·6	1·9	1·6	……	……	3·7
3·8	4·0	4·1	4·1	4·0	3·5	3·1	2·6	2·5	2·2	2·1	2·0	1·6	2·2
4·6	4·9	4·9	4·9	4·7	4·4	3·9	3·3	2·9	2·6	2·1	……	……	3·0
4·0	4·1	3·6	3·3	2·4	1·8	1·0	0·7	0·7	0·6	0·5	……	……	1·5

Sarawak in Borneo, Eastern Archipelago.

4·3	4·8	5·0	4·7	4·6	4·3	3·7	3·3	2·9	2·4	1·9	1·7	1·3	
3·9	4·2	4·2	4·3	4·2	4·4	3·8	3·8	2·8	2·3	2·0	1·8	1·5	
4·0	4·5	5·1	5·1	4·7	4·0	4·1	3·9	2·8	2·4	2·2	1·8	1·6	
12·2	13·5	14·3	14·1	13·5	12·7	11·6	11·0	8·5	7·1	6·1	5·3	4·4	
4·1	4·5	4·8	4·7	4·5	4·2	3·9	3·7	2·8	2·4	2·0	1·8	1·5	2·4

Table C.

Variation of the Wet Thermometer at

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
October ......1847......	......	......	......	0·7	0·5	0·2	0·0	1·7	4·2	6·7	6·9
November	......	......	......	0·4	0·2	0·1	0·0	1·3	4·0	5·9	6·5
December	......	......	......	0·5	0·2	0·0	0·0	1·0	3·9	6·1	7·3
January ......1848......	......	......	......	0·5	0·2	0·0	0·1	0·7	3·3	6·0	6·7
Sums	......	......	......	2·1	1·1	0·3	0·1	4·7	15·4	24·7	27·4
Means and Variation...	......	......	......	0·5	0·3	0·1	0·0	1·2	3·8	6·2	6·8

Variation of the Wet Thermometer at

November ......1848...	......	......	......	0·9	0·7	0·6	0·4	0·0	0·4	0·9	1·3
December	......	......	......	1·0	0·9	0·8	0·0	0·0	0·4	1·1	1·3
Sums	......	......	......	1·9	1·6	1·4	0·4	0·0	0·8	2·0	2·6
Means and Variation...	......	......	......	0·9	0·8	0·7	0·2	0·0	0·4	1·0	1·3

Variation of the Wet Thermometer

November ...1846......	1·1	1·9	0·6	0·4	0·3	0·1	0·0	1·1	2·3	3·3	3·6
December	1·0	0.8	0·7	0·5	0·3	0·1	0·0	0·8	2·2	3·3	3·8
January ......1847......	1·5	1·3	0·9	0·6	0·4	0·1	0·0	0·6	1·8	2·5	3·1
February	1·0	1·0	0·7	0·6	0·4	0·2	0·0	0·4	1·5	2·3	2·8
Sums	4·6	4·0	2·9	2·1	1·4	0·5	0·0	2·9	7·8	11·4	13·3
Means and Variation...	1·1	1·0	0·7	0·5	0·3	0·1	0·0	0·7	1·9	2·8	3·3

Variation of the Bulb Thermometer

March	......	......	......	0·9	0·5	0·2	0·0	0·7	1·8	2·6	3·1
April	......	......	......	1·3	0·6	0·1	0·0	1·0	2·3	3·7	4·3
May	......	......	......	1·3	0·8	0·4	0·0	1·1	2·9	4·4	4·9
June	......	......	......	0·1	0·7	0·2	0·0	0·8	2·4	4·3	4·5
Sums	......	......	......	3·6	2·6	0·9	0·0	3·6	9·4	15·0	16·8
Means and Variation...	......	......	......	0·9	0·6	0·2	0·0	0·9	2·3	3·7	4·2

Diurnal Variation of the Tension of Vapour

	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
Moulmein	......	......	......	·023	·022	·000	·002	·043	·105	·116	·121
Madras	......	......	......	·044	·031	·017	·005	·024	·016	·019	·010
Nicobar	......	......	......	·000	·012	·010	·009	·041	·123	·138	·185
Sambooanga	......	......	......	·000	·001	·014	·002	·069	·138	·185	·168
Pulo Penang	......	......	......	·027	·022	·006	·000	·021	·058	·131	·188
Pulo Dinding............	......	......	......	·040	·018	·011	·000	·031	·071	·165	·200
Sarawak..................	·033	·029	·022	·016	·012	·006	·000	·010	·033	·062	·075
Keemah	......	......	......	·029	·025	·017	·000	·066	·126	·184	·223
Pulo Peesang............	......	......	......	......	·009	·000	·002	·020	·028	·064	·103
Singapore	......	......	......	·023	·019	·017	·004	·000	·006	·017	·021
Carimon..................	......	......	......	......	......	·000	·004	·032	·051	·065	·064
Padang	......	......	......	·012	·006	·002	·000	·026	·078	·133	·130
Bencoolen	......	......	......	·014	·006	·000	·000	·055	·085	·107	·117
Batavia, Winter.........	·023	·021	·015	·011	·007	·001	·000	·013	·037	·047	·047
Batavia, Spring.........	......	......	......	·029	·015	·005	·000	·021	·046	·063	·061
Cocos.....................	......	......	......	·000	·001	·001	000	·004	·019	·056	·059

Table C.

Padang in Sumatra, Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
7·9	8·2	8·2	8·2	7·5	6·9	6·3	5·2	4·3	3·3	3·1	......	......	......
7·2	8·2	8·1	7·9	7·2	6·6	5·5	4·5	4·2	3·4	2·9	......	......	......
8·1	8·8	9·2	8·5	7·4	6·3	5·5	4·5	3·6	2·7	2·4	......	......	......
8·0	8·8	9·6	8·8	8·5	7·9	6·4	4·8	4·2	3·5	2·9	......	......	......
31·2	34·0	35·1	33·4	30·6	27·7	23·7	19·0	16·3	12·9	11·3	......	......	......
7·8	8·5	8·8	8·3	7·6	6·9	5·9	4·7	4·1	3·2	2·8	......	......	4·6

Singapore, Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
1·7	1·9	2·2	2·3	3·0	1·9	1·6	1·8	1·9	1·7	1·6	......	......	1·4
1·6	2·2	2·3	1·8	2·0	1·7	1·4	1·6	1·8	1·7	1·5	......	......	1·3
3·3	4·1	4·5	4·1	5·0	3·6	3·0	3·4	3·7	3·4	3·1	......	......	......
1·6	2·0	2·2	2·0	2·5	1·8	1·5	1·7	1·8	1·7	1·5	......	......	1·3

at Batavia in Java, Eastern Archipelago. Winter.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
4·3	4·8	4·4	4·6	4·5	3·9	3·6	2·9	2·8	2·4	2·1	2·0	1·6	2·4
4·3	4·0	4·1	4·0	3·8	3·2	2·6	2·2	2·1	1·9	1·7	1·7	1·3	2·0
3·4	3·7	4·2	4·2	4·3	4·1	3·8	3·0	2·8	2·7	2·5	2·3	2·0	2·4
3·2	3·4	3·7	3·7	3·3	2·9	2·6	2·3	2·3	1·9	2·0	1·9	1·6	2·0
15·2	15·9	16·4	16·5	15·9	14·1	12·6	10·4	10·0	8·9	8·3	7·9	6·5	8·8
3·8	4·0	4·1	4·1	4·0	3·5	3·1	2·6	2·5	2·2	2·1	2·0	1·6	2·2

at Batavia in Java, Eastern Archipelago. Spring.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
3·5	3·8	3·9	4·2	4·2	3·9	3·3	2·7	2·3	2·0	1·3	......	......	2·4
4·6	4·8	4·7	4·6	4·4	4·1	3·6	3·1	2·6	2·3	1·7	......	......	2·8
5·5	5·6	5·6	5·5	5·3	5·2	4·6	3·9	3·7	3·3	3·0	......	......	3·5
4·8	5·3	5·4	5·3	5·1	4·6	4·3	3·7	3·2	2·9	2·6	......	......	3·2
18·4	19·5	19·6	19·6	19·0	17·8	15·8	13·4	11·8	10·5	8·6	......	......	11·9
4·6	4·9	4·9	4·9	4·7	4·4	3·9	3·3	2·9	2·6	2·1	......	......	3·0

at various Stations in the Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
·109	·114	·085	·024	·021	·015	·010	·010	·025	·039	·034	......	......	·043
·000	·001	·006	·015	·044	·075	·064	·071	·100	·105	·104	......	......	·035
·169	·175	·202	·159	·167	·166	·148	·122	·051	·083	·059	......	......	·105
·137	·171	·177	·219	·201	·202	·164	·146	·124	·100	·090	......	......	·117
·202	·177	·151	·141	·131	·152	·118	·095	·091	·076	·061	......	......	·094
·226	·176	·227	·190	·251	·161	·136	·084	·073	·045	·064	......	......	·104
·077	·077	·081	·077	·079	·082	·078	·092	·074	·062	·053	·046	·037	·049
·257	·291	·193	·205	·184	·162	·161	·143	·128	·106	.096	......	......	·129
·100	·079	·093	·077	·064	·083	·065	·044	·051	·042	......	......	......	·056
·027	·038	·048	·039	·043	·038	·031	·041	·049	·045	·044	......	......	·027
·079	·065	·087	·090	·066	·070	·056	·051	·030	·011	......	......	......	·050
·151	·165	·171	·168	·152	·147	·133	·113	·102	·082	·077	......	......	·093
·123	·140	·151	·154	·119	·127	·122	·091	·059	·041	·037	......	......	·079
·052	·052	·054	·053	·052	·044	·046	·043	·048	·045	·041	·044	·036	·033
·063	·064	·065	·072	·068	·065	·061	·059	·054	·050	·049	......	......	·043
·087	·088	·076	·074	·052	·039	·019	·013	·014	·003	·011	......	......	·032

Table C.

Diurnal Variation of the Tension of Vapour at

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
June ....1846......	·031	·028	·023	·018	·012	·008	·000	·010	·038	·071	·077
July	·035	·030	·021	·013	·011	.006	·000	·009	·029	·061	·080
August	·034	·029	·022	·016	·014	·005	·000	·011	·031	·055	·069
Sums	·100	·087	·066	·047	·037	·019	·000	·030	·098	·187	·226
Means and Variation .	·033	·029	·022	·016	·012	·006	·000	·010	·033	·062	·075

Diurnal Variation of the

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
October......1847......	......	......	......	·019	·015	·006	·000	·040	·085	·141	·125
November	......	......	......	·010	·006	·004	·000	·028	·080	·117	·120
December	......	......	......	·010	·002	·000	·000	·022	·084	·149	·143
January ...1848.........	......	......	......	·013	·005	·000	·004	·018	·067	·127	·134
Sums	......	......	......	·052	·028	·010	·004	·108	·316	·534	·522
Means and Variation .	......	......	......	·012	·006	·002	·000	·026	·078	·133	·130

Diurnal Variation of the

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
November ...1848......	......	......	......	·024	·018	·015	·011	·000	·010	·018	·026
December	......	......	......	·024	·022	·022	·000	·002	·005	·018	·018
Sums	......	......	......	·048	·040	·037	·011	·002	·015	·036	·044
Means	......	......	......	·024	·020	·018	·005	·001	·007	·018	·022
Variation	......	......	......	·023	·019	·017	·004	·000	·006	·017	·021

Diurnal Variation of the

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
November ...1846......	·022	·018	·011	·008	·006	·000	·000	·022	·042	·053	·042
December	·020	·016	·016	·013	·009	·003	·000	·016	·043	·057	·054
January ......1847......	·029	·026	·019	·012	·008	·000	·005	·010	·032	·038	·046
February	·025	·027	·019	·016	·011	·006	·000	·010	·037	·045	·049
Sums	·096	·087	·065	·049	·034	·009	·005	·058	·154	·193	·191
Means	·024	·022	·016	·012	·008	·002	·001	·014	·038	·048	·048
Variation	·023	·021	·015	·011	·007	·001	·000	·013	·037	·047	·047

Diurnal Variation of the

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
March ......1847......	......	......	......	·021	·012	·005	·000	·020	·041	·047	·049
April	......	......	......	·033	·013	·000	·000	·025	·048	·073	·073
May	......	......	......	·034	·020	·012	·000	·027	·057	·071	·076
June	......	......	......	·027	·017	·003	·000	·014	·039	·062	·044
Sums	......	......	......	·115	·063	·020	·000	·086	·185	·253	·242
Means and Variation .	......	......	......	·029	·015	·005	·000	·021	·046	·063	·061

Table C.

Sarawak in the Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
·084	·089	·091	·081	·089	·087	·074	·083	·077	·064	·049	·045	·032	·052
·073	·068	·066	·064	·073	·087	·072	·093	·072	·058	·049	·045	·036	·045
·073	·074	·087	·086	·074	·071	·087	·099	·074	·065	·060	·048	·043	·049
·230	·231	·244	·231	·236	·245	·233	·275	·223	·187	·158	·138	·111	·146
·077	·077	·081	·077	·079	·082	·078	·092	·074	·062	·053	·046	·037	·049

Tension of Vapour at Padang in Sumatra.

·152	·160	·164	·166	·153	·150	·152	·130	·107	·084	·084	......	......	·100
·129	·158	·154	·159	·146	·140	·118	·103	·106	·086	·076	......	......	·088
·160	·162	·177	·159	·134	·124	·116	·107	·090	·064	·065	......	......	·087
·165	·181	·193	·171	·179	·178	·151	·116	·108	·098	·084	......	......	·101
·606	·661	·688	·655	·612	·592	·537	·456	·411	·332	·309	......	......	·376
·151	·165	·171	·168	·152	·147	·133	·113	·102	·082	·077	......	......	·093

Tension of Vapour at Singapore.

·033	·038	·051	·056	·048	·047	·038	·047	·054	·049	·050	......	......	·030
·023	·041	·047	·024	·040	·031	·026	·037	·046	·044	·040	......	......	·036
·056	·079	·098	·080	·088	·078	·064	·084	·100	·093	·090	......	......	·056
·028	·039	·049	·040	·044	·039	·032	·042	·050	·046	·045	......	......	·028
·027	·038	·048	·039	·043	·038	·031	·041	·049	·045	·044	......	......	·027

Tension of Vapour at Batavia. Winter.

·053	·068	·054	·061	·068	·055	·064	·060	·062	·054	·046	·047	·036	·038
·062	·055	·060	·055	·048	·037	·033	·036	·042	·041	·038	·041	·032	·029
·046	·043	·053	·051	·054	·051	·051	·039	·045	·049	·038	·046	·039	·034
·051	·045	·053	·050	·042	·037	·040	·041	·049	·040	·048	·047	·042	·035
·212	·211	·220	·217	·212	·180	·188	·176	·198	·184	·170	·181	·149	·136
·053	·053	·055	·054	·053	·045	·047	·044	·049	·046	·042	·045	·037	·034
·052	·052	·054	·053	·052	·044	·046	·043	·048	·045	·041	·044	·036	·033

Tension of Vapour at Batavia. Spring.

·052	·054	·054	·066	·065	·061	·049	·047	·040	·038	·020	......	......	·039
·075	·074	·069	·074	·065	·059	·055	·055	·041	·039	·022	......	......	·044
·084	·076	·083	·091	·085	·087	·081	·076	·083	·075	·069	......	......	·061
·041	·052	·055	·057	·056	·053	·058	·060	·051	·049	·044	......	......	·040
·252	·256	·261	·288	·271	·260	·243	·238	·215	·201	·155	......	......	·184
·063	·064	·065	·072	·068	·065	·061	·059	·054	·050	·049	......	......	·046

TABLE C.

Mean Degree of Humidity of the Air at

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Moulmein	......	......	......	90	91	89	89	84	72	65	57
Madras	......	......	......	84	83	83	83	81	72	66	60
Nicobar	......	......	......	94	93	93	92	93	88	83	77
Sambooanga	......	......	......	90	90	91	91	85	78	79	77
Pulo Penang	......	......	......	91	91	93	91	91	89	84	80
Pulo Dinding	......	......	......	90	89	90	90	92	81	77	63
Sarawak	97	98	98	98	98	98	99	99	97	93	88
Keemah	......	......	......	93	93	93	92	92	79	77	73
Pulo Peesang	......	......	......	......	98	99	99	98	96	92	83
Singapore	......	......	......	86	86	87	87	88	86	84	82
Carimon	......	......	......	......	......	93	95	91	84	79	74
Padang	......	......	......	94	93	93	93	92	85	79	74
Bencoolen	......	......	......	100	100	100	100	98	89	86	80
Batavia, Winter	93	94	95	96	96	96	97	94	91	85	80
Batavia, Spring	......	......	......	95	96	96	97	95	89	81	78
Cocos	......	......	......	83	84	84	84	84	82	80	78

Mean Degree of Humidity of

June 1846	98	99	99	99	99	99	99	99	97	93	87
July	97	97	97	97	98	97	99	99	97	93	90
August	97	97	97	97	98	98	98	99	97	92	87
Means	97	98	98	98	98	98	99	99	97	93	88

Mean Degree of Humidity of

October.........1847	......	......	......	94	94	93	93	92	84	79	72
November	......	......	......	94	94	94	94	91	84	78	74
December	......	......	......	92	91	92	92	91	86	80	73
January.........1848	......	......	......	94	93	94	94	93	86	80	76
Means	......	......	......	94	93	93	93	92	85	79	74

Mean Degree of Humidity of

November 1848	......	......	......	87	87	87	88	88	88	86	84
December	......	......	......	86	86	87	87	88	85	83	81
Means	......	......	......	86	86	87	87	88	86	84	82

Mean Degree of Humidity

November 1846	93	94	94	95	95	95	97	93	88	82	76
December	93	94	95	96	96	96	96	94	89	83	77
January 1847	93	94	95	96	97	97	98	95	91	86	83
February	95	96	96	97	96	96	96	96	95	89	85
Means	93	94	95	96	96	96	97	94	91	85	80

Mean Degree of Humidity of

March 1847	......	......	......	95	95	96	96	96	92	86	81
April	......	......	......	96	96	96	97	96	91	85	79
May	......	......	......	96	96	97	97	95	88	78	75
June	......	......	......	95	96	96	97	94	87	77	70
Means	......	......	......	95	96	96	97	95	89	81	78

Table C.

various stations in the Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
51	50	47	43	48	50	55	66	74	81	82	......	......	66
55	52	51	52	56	61	65	71	78	81	82	......	......	68
74	74	74	76	77	79	80	86	88	90	91	......	......	84
77	78	73	76	74	77	79	84	84	86	87	......	......	81
76	76	76	77	76	80	82	85	88	88	89	......	......	84
58	58	59	63	70	72	79	84	86	84	88	......	......	76
83	79	78	77	80	82	85	92	95	96	96	97	97	91
72	71	74	78	79	80	85	88	90	90	91	......	......	83
75	70	71	79	85	87	93	94	96	94	96	......	......	88
81	81	82	82	83	84	84	85	87	87	88	......	......	85
69	69	68	68	71	74	78	86	87	87	......	......	......	79
71	69	68	70	73	78	82	88	91	92	94	......	......	83
79	79	81	86	86	86	90	95	95	95	97	......	......	88
76	75	75	75	76	77	81	85	89	90	91	93	93	87
74	71	71	74	74	75	78	84	86	88	89	......	......	83
76	76	77	79	80	81	82	83	83	82	83	......	......	81

the Air at Sarawak, Borneo.

83	79	78	78	81	83	86	93	95	96	96	97	97	92
84	79	79	77	82	83	84	92	95	96	96	97	96	91
82	78	76	75	76	81	86	92	95	96	97	96	97	91
83	79	78	77	80	82	85	92	95	96	96	97	97	91

the Air at Padang in Sumatra.

71	71	72	72	75	80	86	89	91	93	94	......	......	83
70	69	69	72	75	79	82	87	91	92	94	......	......	83
70	65	66	67	70	76	81	88	90	90	94	......	......	81
73	71	67	68	73	77	81	88	91	95	96	......	......	83
71	69	68	70	73	78	82	88	91	92	94	......	......	83

the Air at Singapore.

83	82	84	84	85	85	85	87	88	88	89	......	......	86
80	80	81	81	82	82	83	84	86	86	86	......	......	84
81	81	82	82	83	84	84	85	87	87	88	......	......	85

of the Air at Batavia in Java. Winter.

73	72	72	72	75	77	82	88	90	91	92	93	93	86
75	76	76	76	75	77	82	86	90	92	93	94	94	87
79	76	74	74	77	75	78	81	85	87	87	91	92	86
81	78	78	77	78	80	84	87	90	91	93	94	95	88
76	75	75	75	76	77	81	85	89	90	91	93	93	87

the Air at Batavia in Java. Spring.

79	76	75	76	76	77	79	85	87	89	90	......	......	85
77	74	74	76	76	77	80	84	85	87	88	......	......	84
72	69	71	74	74	76	79	84	89	90	91	......	......	83
67	66	66	67	68	70	75	82	83	86	87	......	......	80
74	71	71	74	74	75	78	84	86	88	89	......	......	83

TABLE C.

Observatory at Moulmein—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Noon.
Dry Thermometer.										
Mean of 7 days......	77·1	76·8	76·6	76·7	79·5	87·1	90·8	95·4	98·5	100·9
Diurnal variation ...	0·5	0·2	0·0	0·1	2·9	10·5	14·2	18·8	21·9	24·3
Wet Thermometer.										
Mean of 7 days......	74·9	74·8	74·2	74·3	76·1	79·7	80·9	82·1	82·6	83·3
Diurnal variation ...	0·7	0·6	0·0	0·1	1·9	5·5	6·7	7·9	8·4	9·1
Tension of vapour...	·826	·825	·803	·805	·846	·908	·919	·924	·912	·917

Observatory at Madras.—Hourly observations made

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Noon.
Dry Thermometer.										
Mean of 32 days ...	78·9	78·6	78·1	77·8	79·2	82·3	85·5	88·2	90·5	92·3
Diurnal variation ...	1·1	0·8	0·3	0·0	1·4	4·5	7·7	10·4	12·7	14·5
Wet Thermometer.										
Mean of 32 days ...	75·0	74·6	74·1	73·7	74·6	75·3	76·3	76·8	77·2	77·7
Diurnal variation ...	1·3	0·9	0·4	0·0	0·9	1·6	1·9	3·1	3·5	4·0
Tension of vapour ...	·810	·797	·783	·771	·790	·782	·785	·776	·766	·767

Observatory at Car Nicobar.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Noon.
Dry Thermometer.										
Mean of 5 days......	73·0	73·6	73·8	73·9	75·0	79·6	82·0	85·8	86·5	86·7
Diurnal variation ...	0·0	0·6	0·8	0·9	2·0	6·6	9·0	12·8	13·5	13·7
Wet Thermometer.										
Mean of 5 days	71·7	72·2	72·2	72·2	73·4	76·8	77·8	79·9	79·7	79·9
Diurnal variation ...	0·0	0·5	0·5	0·5	1·7	5·1	6·1	8·2	8·0	8·2
Tension of vapour...	·750	·762	·760	·759	·791	·873	·885	·935	·919	·925

Observatory at Sambooanga.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Noon.
Dry Thermometer.										
Mean of 6 days......	74·7	74·6	74·8	74·5	79·2	84·1	85·3	85·7	84·5	86·9
Diurnal variation ...	0·2	0·1	0·3	0·0	4·7	9·6	10·8	11·2	10·0	12·4
Wet Thermometer.										
Mean of 6 days	72·5	72·5	72·9	72·5	75·6	78·6	80·0	79·7	78·7	80·1
Diurnal variation ...	0·0	0·0	0·4	0·0	3·1	6·1	7·5	7·2	6·2	7·6
Tension of vapour...	·760	·761	·774	·762	·829	·898	·945	·928	·897	·931

Observatory at Penang.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Noon.
Dry Thermometer.										
Mean of 5 days	76·4	75·9	74·9	75·1	76·0	78·2	82·4	86·0	88·0	86·9
Diurnal variation ...	1·5	1·0	0·0	0·2	1·1	3·3	7·5	11·1	13·1	12·0
Wet Thermometer.										
Mean of 5 days	74·3	74·0	73·3	73·2	74·0	75·6	78·5	80·8	81·6	80·3
Diurnal variation ...	1·3	1·0	0·3	0·2	0·0	2·6	5·5	7·8	8·6	7·8
Tension of vapour...	·809	·804	·788	·782	·803	·840	·913	·970	·984	·959

TABLE C.

made during the Month of April, 1849.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Tension of Vapour.
Dry Thermometer.											
100·3 23·7	100·6 24·0	97·0 20·4	95·4 18·8	92·3 15·7	86·4 9·8	83·2 6·6	81·3 4·7	80·6 4·0	1676·5	88·3	
Wet Thermometer.											
82·6 8·4 ·888	81·3 7·1 ·827	80·3 6·1 ·824	79·7 5·5 ·818	78·8 4·6 ·813	77·2 3·0 ·813	76·7 2·5 ·828	76·5 2·3 ·842	76·2 2·0 ·837	1492·2	78·5	·846

during the Months of August and September, 1849.

Dry Thermometer											
93·3 15·5	92·9 15·1	91·5 13·7	90·0 12·2	87·4 9·6	85·0 7·2	83·2 5·4	82·3 4·5	81·7 3·9	1618·7	85·2	
Wet Thermometer.											
78·1 4·4 ·772	78·2 4·5 ·781	78·5 4·8 ·810	78·2 4·5 ·841	77·9 4·2 ·830	77·4 3·7 ·837	77·6 3·9 ·866	77·5 3·8 ·871	77·3 3·6 ·870	1456·0	76·6 ·801	·801

made during the Month of February, 1849.

Dry Thermometer.											
87·6 14·6	85·5 12·5	85·2 12·2	84·6 11·6	83·3 10·3	80·4 7·4	78·5 5·5	77·6 4·6	76·4 3·4	1529·0	80·5	
Wet Thermometer.											
80·8 9·1 ·952	79·2 7·5 ·909	79·3 7·6 ·917	79·1 7·4 ·916	78·4 6·7 ·898	77·0 5·3 ·872	75·7 4·0 ·841	75·3 3·6 ·835	74·3 2·6 ·809	1454·9	76·6 ·855	·855

made during the Month of May, 1848.

Dry Thermometer.											
87·8 13·3	88·5 14·0	88·0 13·5	86·7 12·2	84·6 10·1	82·3 7·8	81·6 7·1	80·0 5·5	79·1 4·6	1562·9	82·2	
Wet Thermometer.											
80·5 8·0 ·937	81·6 9·1 ·979	81·1 8·6 ·961	80·8 8·3 ·962	79·3 6·8 ·924	78·3 5·8 ·906	77·6 5·1 ·884	76·6 4·1 ·860	76·1 3·6 ·850	1475·0	77·6 ·877	·877

made during the Month of January, 1849.

Dry Thermometer.											
86·3 11·4	85·4 10·5	85·6 10·7	84·8 9·9	82·8 7·9	80·7 5·8	79·6 4·7	79·1 4·2	78·3 3·4	1542·4	81·2	
Wet Thermometer.											
80·0 7·0 ·933	79·5 6·5 ·923	79·3 6·3 ·913	79·6 6·6 ·934	78·3 5·3 ·900	77·2 4·2 ·877	76·8 3·8 ·873	76·3 3·3 ·858	75·7 2·7 ·843	1468·8	77·3 ·876	·876

TABLE C.

Observatory at Pulo Dinding.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Dry Thermometer.													
Mean of 3 days ...	......	......	......	75·3	74·9	74·2	73·9	74·4	79·7	85·0	92·3	96·1	94·4
Diurnal variation ...	......	......	......	1·4	1·0	0·3	0·0	0·5	5·8	11·1	18·4	22·2	20·5
Wet Thermometer.													
Mean of 3 days ...	......	......	......	73·2	72·5	72·1	71·7	72·7	75·3	79·0	81·7	83·2	81·7
Diurnal variation ...	......	......	......	1·5	0·8	0·4	0·0	1·0	3·6	7·3	10·0	11·5	10·0
Tension of vapour...	......	......	......	·780	·758	·751	·740	·771	·811	·905	·940	·966	·916

Observatory at Sarawak.—Hourly observations

Dry Thermometer.													
Mean of 26 days ...	77·0	76·6	76·3	76·1	75·9	75·9	75·5	76·0	77·5	79·8	82·2	84·0	85·4
Diurnal variation ...	1·5	1·1	0·8	0·6	0·4	0·4	0·0	0·5	2·0	4·3	6·7	8·5	9·9
Wet Thermometer.													
Mean of 26 days ...	76·5	76·3	76·1	75·9	75·7	75·6	75·3	75·7	76·8	78·2	79·1	79·6	80·1
Diurnal variation ...	1·2	1·0	0·8	0·6	0·4	0·3	0·0	0·4	1·5	2·9	3·8	4·3	4·8
Tension of vapour...	·890	·887	·882	·877	·871	·867	·859	·869	·897	·930	·936	·943	·948

Observatory at Sarawak.—Hourly observations

Dry Thermometer.													
Mean of 27 days ...	76·6	76·3	76·0	75·7	75·5	75·4	74·8	75·1	76·4	78·6	80·5	82·4	83·9
Diurnal variation ...	1·8	1·5	1·2	0·9	0·7	0·6	0·0	0·3	1·6	3·8	5·7	7·6	9·1
Wet Thermometer.													
Mean of 27 days ...	76·0	75·8	75·5	75·2	75·1	74·9	74·6	74·9	75·8	77·2	77·9	78·5	78·8
Diurnal variation ...	1·4	1·2	0·9	0·6	0·5	0·3	0·0	0·3	1·2	2·6	3·3	3·9	4·2
Tension of vapour...	·875	·870	·861	·853	·851	·846	·840	·849	·869	·901	·920	·913	·908

Observatory at Sarawak.—Hourly observations

Dry Thermometer.													
Mean of 19 days ...	76·2	75·9	75·6	75·4	75·2	74·9	74·6	74·8	76·1	78·6	80·7	82·6	84·3
Diurnal variation ...	1·6	1·3	1·0	0·8	0·6	0·3	0·0	0·2	1·5	4·0	6·1	8·0	9·7
Wet Thermometer.													
Mean of 19 days ...	75·5	75·3	75·0	74·8	74·7	74·4	74·2	74·5	75·4	76·7	77·6	78·2	78·7
Diurnal variation ...	1·3	1·1	0·8	0·6	0·5	0·2	0·0	0·3	1·2	2·5	3·4	4·0	4·5
Tension of vapour...	·859	·854	·847	·841	·839	·830	·825	·836	·856	·880	·894	·898	·899

Observatory at Keemah.—Hourly observations

Dry Thermometer.													
Mean of 10 days ...	......	......	......	74·0	73·7	73·4	73·0	75·7	82·4	85·3	88·6	90·1	91·6
Diurnal variation ...	......	......	......	1·0	0·7	0·4	0·0	2·7	9·4	12·3	15·6	17·1	18·6
Wet Thermometer.													
Mean of 10 days ...	......	......	......	72·4	72·2	71·9	71·3	73·9	77·3	79·4	81·2	82·3	83·4
Diurnal variation ...	......	......	......	1·1	0·9	0·6	0·0	2·6	6·0	8·1	9·9	11·0	12·1
Tension of vapour...	......	......	......	·765	·761	·753	·736	·802	·862	·920	·959	·993	1·027

TABLE C.

made during the Month of January, 1849.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Tension of Vapour.
Dry Thermometer.													
95·7 21·8	92·4 18·5	90·3 16·4	87·0 13·1	83·0 9·1	79·3 5·4	78·2 4·3	77·9 4·0	77·2 3·3	....	....	1581·2	83·2	
Wet Thermometer.													
83·1 11·4 ·967	81·5 9·8 ·930	82·3 10·6 ·996	79·4 7·7 ·901	77·8 6·1 ·876	75·5 3·8 ·824	74·9 3·2 ·813	74·1 2·4 ·785	74·4 2·7 ·804	....	....	1466·1	77·1 ·844	·844

made during the Month of June, 1846.

Dry Thermometer.													
85·9 10·4	85·7 10·2	84·7 9·2	83·8 8·3	82·5 7·0	80·2 4·7	79·2 3·7	78·5 3·0	78·0 2·5	77·6 2·1	77·3 1·8	1911·6	79·6	
Wet Thermometer.													
80·3 5·0 ·950	80·0 4·7 ·940	79·9 4·6 ·948	79·6 4·3 ·946	79·0 3·7 ·933	78·6 3·3 ·942	78·2 2·9 ·936	77·7 2·4 ·923	77·2 1·9 ·908	77·0 1·7 ·904	76·6 1·3 ·891	1865·0	77·7 ·911	·911

made during the Month of July, 1846.

Dry Thermometer.													
84·1 9·3	84·6 9·8	83·5 8·7	83·1 8·3	82·1 7·3	80·2 5·4	78·4 3·6	77·8 3·0	77·5 2·7	77·1 2·3	76·8 2·0	1892·4	78·9	
Wet Thermometer.													
78·8 4·2 ·906	78·9 4·3 ·904	78·8 4·2 ·913	79·0 4·4 ·927	78·4 3·8 ·912	78·4 3·8 ·933	77·4 2·8 ·912	76·9 2·3 ·898	76·6 2·0 ·889	76·4 1·8 ·885	76·1 1·5 ·876	1845·9	76·9 ·885	·885

made during the Month of August, 1846.

Dry Thermometer.													
85·6 11·0	85·7 11·1	85·1 10·5	82·8 9·2	81·7 7·1	79·9 5·3	78·1 3·5	77·4 2·8	77·1 2·5	76·8 2·2	76·5 1·9	1891·6	78·8	
Wet Thermometer.													
79·3 5·1 ·912	79·3 5·1 ·911	78·9 4·7 ·899	78·2 4·0 ·896	78·3 4·1 ·912	78·1 3·9 ·924	77·0 2·8 ·899	76·6 2·4 ·890	76·4 2·2 ·885	76·0 1·8 ·873	75·8 1·6 ·868	1838·9	76·6 ·874	·874

made during the Month of June, 1848.

Dry Thermometer.													
87·1 14·1	85·6 12·6	84·6 11·6	83·7 10·7	81·5 8·5	79·8 6·8	78·6 5·6	77·7 4·7	77·0 4·0	....	....	1543·4	81·1	
Wet Thermometer.													
80·1 8·8 ·929	80·0 8·7 ·941	79·2 7·9 ·920	78·5 7·2 ·898	77·9 6·6 ·897	77·0 5·7 ·879	76·3 5·0 ·864	75·5 4·2 ·842	75·0 3·7 ·832	....	....	1464·8	77·0 ·865	·865

TABLE C.

Observatory at Pulo Peesang.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Dry Thermometer.										
Mean of 5 days	......	75·9	75·1	75·3	76·1	77·1	80·1	84·3	87·1	88·6
Diurnal variation	......	0·8	0·0	0·2	1·0	2·0	5·0	9·2	12·0	13·5
Wet Thermometer.										
Mean of 5 days	......	75·4	74·9	75·0	75·7	76·2	77·9	79·9	80·6	80·5
Diurnal variation ...	......	0·5	0·0	0·1	0·8	1·3	3·0	5·0	5·7	5·6
Tension of vapour ...	......	·858	·849	·851	·869	·877	·913	·952	·949	·928

Observatory at Singapore.—Hourly observations

Dry Thermometer.										
Mean of 16 days ...	79·4	79·2	79·1	78·8	78·3	78·9	79·9	80·7	81·5	81·8
Diurnal variation ...	1·1	0·9	0·8	0·5	0·0	0·6	1·6	2·4	3·2	3·5
Wet Thermometer.										
Mean of 16 days ...	76·5	76·3	76·2	76·0	75·6	76·0	76·5	76·9	77·3	77·5
Diurnal variation ...	0·9	0·7	0·6	0·4	0·0	0·4	0·9	1·3	1·7	1·9
Tension of vapour ...	·863	·857	·854	·850	·839	·849	·857	·865	·872	·877

Observatory at Singapore.—Hourly observations

Dry Thermometer.										
Mean of 14 days ...	79·2	79·0	78·7	77·9	77·7	78·8	80·2	80·8	81·4	82·0
Diurnal variation ...	1·5	1·3	1·0	0·2	0·0	1·1	2·5	3·1	3·7	4·3
Wet Thermometer.										
Mean of 14 days ...	75·9	75·8	75·7	74·9	74·9	75·3	76·0	76·2	76·5	77·1
Diurnal variation ...	1·0	0·9	0·8	0·0	0·0	0·4	1·1	1·3	1·6	2·2
Tension of vapour ...	·841	·839	·839	·817	·819	·822	·835	·835	·840	·858

Observatory at Carimon Island.—Hourly observations

Dry Thermometer.										
Mean of 6 days	......	......	76·9	76·3	78·7	81·8	84·3	86·1	89·1	88·5
Diurnal variation ...	......	......	0·6	0·0	2·4	5·5	8·0	9·8	12·8	12·2
Wet Thermometer.										
Mean of 6 days	......	......	75·3	75·2	76·6	77·9	78·9	79·3	80·5	80·0
Diurnal variation ...	......	......	0·1	0·0	1·4	2·7	3·7	4·1	5·3	4·8
Tension of vapour ...	......	......	·843	·847	·875	·894	·908	·907	·922	·908

Observatory at Padang.—Hourly observations

Dry Thermometer.										
Mean of 13 days ...	72·9	72·7	72·5	72·4	74·4	78·9	82·9	85·0	86·4	87·0
Diurnal variation ...	0·5	0·3	0·1	0·0	2·0	6·5	10·5	12·6	14·0	14·6
Wet Thermometer.										
Mean of 13 days ...	71·6	71·4	71·1	70·9	72·6	75·1	77·6	77·8	78·8	79·1
Diurnal variation ...	0·7	0·5	0·2	0·0	1·7	4·2	6·7	6·9	7·9	8·2
Tension of vapour ...	·747	·743	·734	·728	·768	·813	·869	·853	·880	·888

Table C.

made during the Month of January, 1846.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Tension of Vapour.
Dry Thermometer.											
88·8 13·7	84·8 9·7	82·4 7·3	81·8 6·7	79·3 4·2	78·2 3·1	78·0 2·9	78·1 3·0	77·2 2·1	1448·2	80·8	
Wet Thermometer.											
80·9 6·0 ·942	79·4 4·5 ·926	78·5 3·6 ·913	78·8 3·9 ·932	77·7 2·8 ·914	76·9 2·0 ·893	77·0 2·1 ·900	76·8 1·9 ·891	76·4 1·5 ·884	1398·5	77·9 ·905	·905

made during the Month of November, 1848.

Dry Thermometer.											
81·8 3·5	81·7 3·4	81·3 3·0	81·0 2·7	80·7 2·4	80·6 2·3	80·4 2·1	80·1 1·8	79·7 1·4	1524·9	80·3	
Wet Thermometer.											
77·8 2·2 ·890	77·9 2·3 ·895	77·6 3·0 ·887	77·5 1·9 ·886	77·2 1·6 ·877	77·4 1·8 ·886	77·5 1·9 ·893	77·3 1·7 ·888	77·2 1·6 ·889	1462·2	76·9 ·869	·869

made during the Month of December, 1848.

Dry Thermometer.											
81·9 4·2	81·2 3·5	81·2 3·5	81·1 3·4	80·5 2·8	80·2 2·5	80·1 2·4	79·9 2·2	79·6 1·9	1522·5	80·1	
Wet Thermometer.											
77·2 2·3 ·864	76·7 1·8 ·841	76·9 2·0 ·857	76·6 1·7 ·848	76·3 1·4 ·843	76·5 1·6 ·854	76·7 1·8 ·863	76·6 1·7 ·861	76·4 1·5 ·857	1448·2	76·2 ·843	·843

made during the Month of January, 1846.

Dry Thermometer.											
89·3 13·0	89·6 13·3	87·4 11·1	86·3 10·0	84·3 8·0	81·0 4·7	80·0 3·7	79·1 2·8	......	1338·7	83·8	
Wet Thermometer.											
80·5 5·3 ·920	80·9 5·7 ·933	79·7 4·5 ·909	79·5 4·3 ·913	78·7 3·5 ·899	77·7 2·5 ·894	76·9 1·7 ·873	76·2 1·0 ·854	....	1253·8	78·4 ·893	·893

made during the Month of October, 1847.

Dry Thermometer.											
86·7 14·3	86·5 14·1	84·8 12·4	82·8 10·4	80·5 8·1	78·7 6·3	77·3 4·9	75·8 3·4	75·2 2·8	1513·4	79·7	
Wet Thermometer.											
79·1 8·2 ·892	79·1 8·2 ·894	78·4 7·5 ·881	77·8 6·9 ·878	77·2 6·3 ·880	76·1 5·2 ·858	75·2 4·3 ·835	74·2 3·3 ·812	74·0 3·1 ·812	1437·1	75·7 ·828	·828

Table C.

Observatory at Padang.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Dry Thermometer.													
Mean of 26 days ...	......	......	......	73·4	73·1	72·9	72·9	74·8	79·4	83·0	85·0	86·7	88·2
Diurnal variation ...	......	......	......	0·5	0·2	0·0	0·0	1·9	6·5	10·1	12·1	13·8	15·3
Wet Thermometer.													
Mean of 26 days ...	......	......	......	72·0	71·8	71·7	71·6	72·9	75·6	77·5	78·1	78·8	79·8
Diurnal variation ...	......	......	......	0·4	0·2	0·1	0·0	1·3	4·0	5·9	6·5	7·2	8·2
Tension of vapour...	......	......	......	·757	·753	·751	·747	·775	·827	·864	·867	·876	·905

Observatory at Padang.—Hourly observations

Dry Thermometer.													
Mean of 26 days ...	......	......	......	73·7	73·4	73·1	73·1	74·3	78·6	83·0	85·8	87·5	89·9
Diurnal variation ...	......	......	......	0·6	0·3	0·0	0·0	1·2	5·5	9·9	12·7	14·4	16·8
Wet Thermometer.													
Mean of 26 days ...	......	......	......	71·9	71·6	71·4	71·4	72·4	75·3	77·5	78·7	79·5	80·2
Diurnal variation ...	......	......	......	0·5	0·2	0·0	0·0	1·0	3·9	6·1	7·3	8·1	8·8
Tension of vapour...	......	......	......	·749	·741	·739	·739	·761	·823	·888	·882	·899	·901

Observatory at Padang.—Hourly observations

Dry Thermometer.													
Mean of 13 days ...	......	......	......	73·8	73·5	73·3	73·3	74·2	78·5	82·9	84·9	87·2	88·7
Diurnal variation ...	......	......	......	0·5	0·2	0·0	0·0	0·9	5·2	9·6	11·6	13·9	15·4
Wet Thermometer.													
Mean of 13 days ...	......	......	......	72·4	72·1	71·9	72·0	72·6	75·2	77·9	78·6	79·9	80·7
Diurnal variation ...	......	......	......	0·5	0·2	0·0	0·1	0·7	3·3	6·0	6·7	8·0	8·8
Tension of vapour...	......	......	......	·767	·759	·754	·758	·770	·821	·881	·888	·919	·935

Observatory at Poolo Bay.—Hourly observations

Dry Thermometer.													
Mean of 5 days ...	......	......	......	73·4	73·2	72·0	73·0	76·0	79·1	81·7	84·3	84·9	85·6
Diurnal variation ...	......	......	......	1·4	1·2	0·0	1·0	4·0	7·1	9·7	12·3	12·9	13·6
Wet Thermometer.													
Mean of 5 days ...	......	......	......	73·8	73·5	73·3	73·3	75·5	77·1	78·3	79·2	79·5	80·1
Diurnal variation ...	......	......	......	0·5	0·2	0·0	0·0	2·2	3·8	5·0	5·9	6·2	6·8
Tension of vapour...	......	......	......	·820	·812	·806	·806	·861	·891	·913	·923	·929	·946

Observatory at Batavia.—Hourly observations

Dry Thermometer.													
Mean of 19 days ...	77·0	76·6	76·3	75·9	75·7	75·5	75·1	77·0	79·5	82·2	84·3	85·9	86·7
Diurnal variation ...	1·9	1·5	1·2	0·8	0·6	0·4	0·0	1·9	4·4	7·1	9·2	10·6	11·6
Wet Thermometer.													
Mean of 19 days ...	75·5	75·3	75·0	74·8	74·7	74·5	74·4	75·5	76·7	77·7	78·0	78·7	79·2
Diurnal variation ...	1·1	0·9	0·6	0·4	0·3	0·1	0·0	1·1	2·3	3·3	3·6	4·3	4·8
Tension of vapour...	·850	·846	·839	·836	·834	·828	·828	·850	·870	·881	·870	·881	·896

TABLE C.

made during the Month of November, 1847.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Tension of Vapour.
Dry Thermometer.													
88·1	86·9	85·2	83·6	81·4	79·1	77·8	76·8	75·9	......	......	1524·2	80·2	
15·2	14·0	12·3	10·7	8·5	6·2	4·9	3·9	3·0					
Wet Thermometer.													
79·7	79·5	78·8	78·2	77·1	76·1	75·8	75·0	74·5	......	......	1444·5	76·0	·835
8·1	7·9	7·2	6·6	5·5	4·5	4·2	3·4	2·9					
·901	·906	·893	·887	·865	·850	·853	·833	·823	......	......	.....	·835	

made during the Month of December, 1847.

Dry Thermometer.													
90·0	89·0	87·0	83·8	81·6	78·8	77·2	76·3	75·2	......	......	1531·3	80·6	
16·9	15·9	13·9	10·7	8·5	5·7	4·1	3·2	2·1					
Wet Thermometer.													
80·6	79·9	78·8	77·7	76·9	75·9	75·0	74·1	73·8	......	......	1442·6	75·9	·826
9·2	8·5	7·4	6·3	5·5	4·5	3·6	2·7	2·4					
·916	·898	·873	·863	·855	·846	·829	·803	·804	......	......	......	·826	

made during the Month of January, 1848.

Dry Thermometer.													
90·9	89·6	87·8	85·8	83·2	79·5	78·0	76·5	75·7	......	......	1537·3	80·9	
17·6	16·3	14·5	12·5	9·9	6·2	4·7	3·2	2·4	......	......			
Wet Thermometer.													
81·5	80·7	80·4	79·8	78·3	76·7	76·1	75·4	74·8	......	......	1457·0	76·7	·855
9·6	8·8	8·5	7·9	6·4	4·8	4·2	3·5	2·9	......	......			
·947	·925	·933	·932	·905	·870	·862	·852	·838	......	......	......	·855	

made during the Months of August and September, 1847.

Dry Thermometer.													
85·0	83·3	82·0	82·5	80·7	78·2	77·1	76·3	75·6	......	......	1504·9	79·3	
13·0	11·3	10·0	10·5	8·7	6·2	5·1	4·3	3·6	......	......			
Wet Thermometer.													
80·2	79·8	78·7	79·0	78·4	77·0	75·9	75·2	74·9	......	......	1462·7	77·0	·865
6·9	6·5	5·4	5·7	5·1	3·7	2·6	1·9	1·6	......	......			
·957	·960	·925	·933	·928	·897	·865	·847	·843	......	......	......	·865	

made during the Month of November, 1846.

Dry Thermometer.													
86·2	86·4	85·3	84·3	82·4	80·1	79·6	78·9	78·4	78·0	77·6	1924·9	80·2	
11·1	11·3	10·2	9·2	7·3	5·0	4·5	3·8	1·3	2·9	2·5			
Wet Thermometer.													
78·8	79·0	78·9	78·3	78·0	77·3	77·2	76·8	76·5	76·4	76.0	1843·2	76·8	·866
4·4	4·6	4·5	3·9	3·6	2·9	2·8	2·4	2·1	2·0	1·6			
·882	·889	·896	·883	·892	·888	·890	·882	·874	·875	·864	......	·866	

TABLE C.

Observatory at Batavia.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Dry Thermometer.													
Mean of 26 days ...	77·0	76·6	76·3	76·0	75·6	75·4	75·3	76·6	79·2	82·0	84·2	85·3	84·8
Diurnal variation ...	1·7	1·3	1·0	0·7	0·3	0·1	0·0	1·3	3·9	6·7	8·9	10·0	9·5
Wet Thermometer.													
Mean of 26 days ...	75·5	75·3	75·2	75·0	74·8	74·6	74·5	75·3	76·7	77·8	78·3	78·8	78·5
Diurnal variation ...	1·0	0·8	0·7	0·5	0·3	0·1	0·0	0·8	2·2	3·3	3·8	4·3	4·0
Tension of vapour ...	·850	·846	·846	·843	·839	·833	·830	·846	·873	·887	·884	·892	·885

Observatory at Batavia.—Hourly observations

Dry Thermometer.													
Mean of 25 days ...	77·1	76·6	76·0	75·5	75·1	74·8	74·6	75·7	77·9	79·8	81·3	82·6	83·8
Diurnal variation ...	2·5	2·0	1·4	0·9	0·5	0·2	0·0	1·1	3·3	5·2	6·7	8·0	9·2
Wet Thermometer.													
Mean of 25 days ...	75·5	75·3	74·9	74·6	74·4	74·1	74·0	74·6	75·8	76·5	77·1	77·4	77·7
Diurnal variation ...	1·5	1·3	0·9	0·6	0·4	0·1	0·0	0·6	1·8	2·5	3·1	3·4	3·7
Tension of vapour ...	·849	·846	·839	·832	·828	·820	·825	·830	·852	·858	·866	·864	·863

Observatory at Batavia.—Hourly observations

Dry Thermometer.													
Mean of 24 days ...	76·9	76·7	76·3	76·1	76·0	75·8	75·6	76·1	77·5	79·7	81·2	82·6	83·8
Diurnal variation ...	1·3	1·1	0·7	0·5	0·4	0·2	0·0	0·5	1·9	4·1	5·6	7·0	8·2
Wet Thermometer.													
Mean of 24 days ...	75·8	75·8	75·5	75·4	75·2	75·0	74·8	75·2	76·3	77·1	77·6	78·0	78·2
Diurnal variation ...	1·0	1·0	0·7	0·6	0·4	0·2	0·0	0·4	1·5	2·3	2·8	3·2	3·4
Tension of vapour ...	·864	·866	·858	·855	·850	·845	·839	·849	·876	·884	·888	·890	·884

Observatory at Batavia.—Hourly observations

Dry Thermometer.													
Mean of 27 days ...	......	......	......	77·3	76·8	76·3	76·1	76·8	78·8	81·2	83·0	84·2	85·1
Diurnal variation ...	......	......	......	1·2	0·7	0·2	0·0	0·7	2·7	5·1	6·9	8·1	9·0
Wet Thermometer.													
Means of 27 days ...	......	......	......	76·1	75·7	75·4	75·2	75·9	77·0	77·8	78·3	78·7	79·0
Diurnal variation ...	......	......	......	0·9	0·5	0·2	0·0	0·7	1·8	2·6	3·1	3·5	3·8
Tension of vapour ...	......	......	......	·870	·861	·854	·849	·869	·890	·896	·898	·901	·903

Observatory at Batavia.—Hourly observations

Dry Thermometer.													
Mean of 26 days ...	......	......	......	76·7	76·0	75·4	75·0	76·3	78·9	81·9	84·1	85·2	86·1
Diurnal variation ...	......	......	......	1·7	1·0	0·4	0·0	1·3	3·9	6·9	9·1	10·2	11·1
Wet Thermometer.													
Mean of 26 days ...	......	......	......	75·8	75·1	74·6	74·5	75·5	76·8	78·2	78·8	79·1	79·3
Diurnal variation ...	......	......	......	1·3	0·6	0·1	0·0	1·0	2·3	3·7	4·3	4·6	4·8
Tension of vapour ...	......	......	......	·866	·846	·833	·833	·858	·881	·906	·906	·908	·907

Table C.

made during the Month of December, 1846.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.	Tension of Vapour.
Dry Thermometer.													
84·8 9·5	84·8 9·5	84·7 9·4	83·4 8·1	81·6 6·3	79·9 4·6	79·0 3·7	78·3 3·0	77·9 2·6	77·6 2·3	77·0 1·7	1913·3	79·7	
Wet Thermometer.													
78·6 4·1 ·890	78·5 4·0 ·885	78·3 3·8 ·878	77·7 3·2 ·867	77·1 2·6 ·863	76·7 2·2 ·866	76·6 2·1 ·872	76·4 1·9 ·871	76·2 1·7 ·868	76·2 1·7 ·871	75·8 1·3 ·862	1838·4 ·859	76·5	·859

made during the Month of January, 1847.

Dry Thermometer.													
84·8 10·2	85·0 10·4	85·1 10·5	84·6 10·0	83·4 8·8	81·6 7·0	80·3 5·7	79·6 5·0	79·1 4·5	78·4 +3·8	77·8 3·2	1910·5	79·8	
Wet Thermometer.													
78·2 4·2 ·73	78·2 4·2 ·871	78·3 4·3 ·874	78·1 4·1 ·871	77·8 3·8 ·871	77·0 3·0 ·859	76·8 2·8 ·865	76·7 2·7 ·869	76·5 2·5 ·858	76·3 2·3 ·866	76·0 2·0 ·859	1831·8	76·4 ·854	

made during the Month of February, 1847.

Dry Thermometer.													
84·2 8·6	84·5 8·9	83·7 8·1	82·6 7·0	81·3 5·7	80·1 4·5	79·4 3·8	78·7 3·1	78·4 2·8	78·1 2·5	77·5 1·9	1902·8	79·5	
Wet Thermometer.													
78·5 3·7 ·892	78·5 3·7 ·889	78·1 3·3 ·881	77·7 2·9 ·876	77·4 2·6 ·879	77·1 2·3 ·880	77·1 2·3 ·888	76·7 1·9 ·879	76·8 2·0 ·887	76·7 1·9 ·886	76·4 1·6 ·881	1840·9	76·8 ·874	·874

made during the Month of March, 1847.

Dry Thermometer.													
85·7 9·6	85·7 9·6	85·8 9·7	85·1 9·0	83·7 7·6	81·6 5·5	80·7 4·6	79·8 3·7	78·9 2·8	....	....	1542·6	81·2	
Wet Thermometer.													
79·1 3·9 ·903	79·4 4·2 ·915	79·4 4·2 ·914	79·1 3·9 ·910	78·5 3·3 ·898	77·9 2·7 ·896	77·5 2·3 ·889	77·2 2·0 ·887	76·5 1·3 ·869	....	....	1473·7	77·6 ·888	·888

made during the Month of April, 1847.

Dry Thermometer.													
86·1 11·1	85·4 10·4	85·1 10·1	84·6 9·6	83·1 8·1	81·6 6·6	80·6 5·6	79·7 4·7	79·0 4·0	....	....	1540·8	81·1	
Wet Thermometer.													
79·2 4·7 ·902	79·1 4·6 ·907	78·9 4·4 ·898	78·6 4·1 ·892	78·1 3·6 ·888	77·6 3·1 ·883	77·1 2·6 ·874	76·8 2·3 ·872	76·2 1·7 ·855	....	....	1469·3	77·3 ·877	·877

TABLE C.

Observatory at Batavia.—Hourly observations

Astron. Mean Time of Station.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Dry Thermometer.										
Mean of 26 days ...	75·5	75·0	74·4	74·0	75·4	79·0	83·2	84·7	86·2	87·3
Diurnal variation ...	1·5	1·0	0·4	0·0	1·4	5·0	9·2	10·7	12·2	13·3
Wet Thermometer.										
Mean of 26 days ...	74·6	74·1	73·7	73·3	74·4	76·2	77·7	78·2	78·8	78·9
Diurnal variation ...	1·3	0·8	0·4	0·0	1·1	2·9	4·4	4·9	5·5	5·6
Tension of vapour...	·832	·818	·810	·798	·825	·855	·869	·874	·882	.874

Observatory at Batavia.—Hourly observations

Dry Thermometer.										
Mean of 26 days ...	74·6	74·1	73·6	73·2	74·6	78·0	82·5	84·9	86·3	87·1
Diurnal variation ...	1·4	0·9	0·4	0·0	1·4	4·8	9·3	11·7	13·1	13·9
Wet Thermometer.										
Mean of 26 days ...	73·6	73·2	72·7	72·5	73·3	74·9	76·8	77·0	77·3	77·8
Diurnal variation ...	0·1	0·7	0·2	0·0	0·8	2·4	4·3	4·5	4·8	5·3
Tension of vapour ...	·804	·794	·780	·777	·791	·816	·839	·821	·818	·829

Observatory at Cocos Island.—Hourly observations made

Dry Thermometer.										
Mean of 27 days ...	77·5	77·4	77·4	77·1	77·5	78·8	80·6	81·9	83·5	83·8
Diurnal variation ...	0·4	0·3	0·3	0·0	0·4	1·7	3·5	4·8	6·4	6·7
Wet Thermometer.										
Mean of 27 days ...	73·6	73·6	73·6	73·5	73·7	74·5	75·7	76·4	77·5	77·6
Diurnal variation ...	0·1	0·1	0·1	0·0	0·2	1·0	2·2	2·9	4·0	4·1
Tension of vapour...	·771	·772	·772	·771	·775	·790	·817	·830	·858	·859

ABLE C.

made during the Month of May, 1847.

1.	2.	3.	4.	5.	6.	7.	8.	9.	Sums.	Means.	Tension of vapour.
Dry Thermometer.											
86·6	85·6	85·4	84·8	83·1	81·0	79·6	78·9	78·3	1538·0	80·9	
12·6	11·6	11·4	10·8	9·1	7·0	5·6	4·9	4·3			
Wet Thermometer.											
78·9	78·8	78·6	78·5	77·9	77·2	77·0	76·6	76·3	1459·7	76·8	·859
5·6	5·5	5·3	5·2	4·6	3·9	3·7	3·3	3·0			
·881	·889	·883	·885	·879	·874	·881	·873	·867	……	·859	

made during the Month of June, 1847.

Dry Thermometer.											
87·2	86·7	86·1	84·5	83·0	80·6	79·6	78·7	78·2	1533·5	80·7	
14·0	13·5	12·9	11·3	9·8	7·4	6·4	5·5	5·0			
Wet Thermometer.											
77·9	77·8	77·6	77·1	76·8	76·2	75·7	75·4	75·1	1438·7	75·7	·817
5·4	5·3	5·1	4·6	4·3	3·7	3·2	2·9	2·6			
·832	·834	·833	·830	·835	·837	·828	·826	·821	……	·817	

during the Months of August and September, 1848.

Dry Thermometer.											
83·0	82·1	80·8	79·8	78·8	78·2	78·0	78·1	77·9	1512·2	79·5	
5·9	5·0	3·8	2·8	1·8	1·2	1·0	1·1	0·9			
Wet Thermometer.											
77·1	76·8	75·9	75·3	74·5	74·2	74·2	74·1	74·0	1425·8	75·0	·803
3·6	3·3	2·4	1·8	1·0	0·7	0·7	0·6	0·5			
·847	·845	·823	·810	·790	·784	·785	·774	·782	……	·803	

TABLE D.

Variation of the Barometer, corrected to 32°, at

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
Moulmein	......	......	......	·049	·044	·053	·063	·077	·102	·120	·131
Madras	......	......	......	·023	·022	·027	·032	·047	·064	·075	·073
Nicobar	......	......	......	·022	·024	·025	·026	·042	·066	·085	·098
Sambooanga	......	......	......	·025	·029	·036	·045	·065	·083	·091	·090
Penang	......	......	......	·051	·048	·053	·061	·075	·096	·112	·106
Pulo Dinding	......	......	......	·037	·033	·034	·038	·041	·055	·069	·081
Sarawak	·093	·082	·065	·057	·051	·057	·069	·085	·100	·109	·107
Keemah	......	......	......	·031	·035	·040	·048	·066	·084	·087	·087
Pulo Peesang	......	......	......	......	·057	·056	·066	·088	·108	·111	·116
Singapore	......	......	......	·034	·036	·044	·058	·080	·098	·103	·098
Carimon	......	......	......	......	......	·065	·079	·100	·115	·118	·117
Padang	......	......	......	·038	·036	·042	·056	·078	·098	·103	·101
Bencoolen	......	......	......	·028	·028	·024	·030	·032	·053	·065	·062
Batavia, Winter	·078	·064	·052	·045	·046	·053	·068	·089	·110	·114	·107
Batavia, Spring	......	......	......	·037	·040	·055	·066	·083	·101	·108	·103
Cocos	......	......	......	·018	·016	·023	·036	·053	·069	·080	·076

Variation of the Barometer, corrected to 32°, at

June ....1846...	·084	·081	·062	·054	·049	·054	·065	·083	·097	·103	·102
July	·091	·077	·062	·055	·050	·053	·064	·081	·096	·103	·102
August	·103	·087	·071	·062	·055	·063	·077	·091	·106	·120	·116
Sums	·278	·245	·195	·171	·154	·170	·206	·255	·299	·326	·320
Means and Variation	·093	·082	·065	·057	·051	·057	·069	·085	·100	·109	·107

Variation of the Barometer, corrected to 32°, at

October.........1847...	......	......	......	·029	·031	·038	·052	·073	·095	·099	·104
November	......	......	......	·041	·040	·048	·062	·085	·106	·111	·107
December	......	......	......	·038	·032	·037	·048	·071	·088	·095	·090
January ....1848...	......	......	......	·048	·044	·049	·067	·090	·107	·112	·106
Sums	......	......	......	·156	·147	·172	·229	·319	·396	·417	·407
Means	......	......	......	·039	·037	·043	·057	·079	·099	·104	·102
Variation	......	......	......	·038	·036	·042	·056	·078	·098	·103	·101

Variation of the Barometer, corrected to 32°, at

November ......1848...	......	......	......	·034	·037	·049	·061	·086	·103	·106	·102
December	......	......	......	·035	·035	·040	·056	·074	·093	·100	·095
Means and Variation	......	......	......	·034	·036	·044	·058	·080	·098	·103	·098

TABLE D.

various Stations in the Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
·121	·109	·087	·055	·019	·004	·000	·002	·013	·026	·037	......	......	·058
·064	·054	·040	·025	·011	·002	·000	·007	·017	·030	·043	......	......	·035
·087	·071	·043	·021	·002	·001	·000	·008	·021	·032	·044	......	......	·038
·079	·063	·044	·025	·008	·000	·015	·030	·048	·059	·075	......	......	·049
·103	·090	·071	·045	·011	·000	·019	·023	·031	·041	·053	......	......	·057
·081	·070	·057	·028	·004	·001	·000	·001	·006	·010	·021	......	......	·035
·091	·070	·044	·018	·001	·000	·006	·020	·044	·062	·085	·098	·099	·068
·073	·061	·039	·020	·008	·000	·010	·023	·044	·058	·075	......	......	·045
·083	·052	·030	·014	·001	·000	·009	·025	·035	·049	·061	......	......	·053
·084	·061	·037	·012	·000	·001	·013	·034	·052	·066	·073	......	......	·052
·106	·082	·062	·014	·004	·000	·005	·027	·032	·049	......	......	......	·061
·087	·064	·038	·014	·000	·000	·011	·032	·051	·070	·080	......	......	·052
·051	·036	·026	·009	·000	·008	·013	·021	·033	·043	·050	......	......	·032
·091	·066	·041	·017	·001	·000	·012	·032	·052	·073	·088	·100	·095	·061
·088	·065	·042	·019	·000	·001	·010	·026	·038	·049	·060	......	......	·054
·064	·043	·027	·011	·000	·002	·012	·025	·044	·060	·071	......	......	·038

Sarawak in Borneo, Eastern Archipelago.

·085	·065	·041	·016	·000	·001	·008	·020	·039	·058	·074	·085	·086	·061
·086	·066	·042	·020	·004	·000	·002	·013	·032	·052	·079	·094	·093	·059
·102	·079	·049	·019	·000	·001	·008	·027	·060	·077	·102	·116	·118	·071
·273	·210	·132	·055	·004	·002	·018	·060	·131	·187	·255	·295	·297	·191
·091	·070	·044	·018	·001	·000	·006	·020	·044	·062	·085	·098	·099	·064

Padang in Sumatra, Eastern Archipelago.

·088	·063	·034	·010	·002	·000	·011	·035	·048	·065	·073	......	......	·050
·093	·066	·039	·017	·000	·003	·015	·038	·057	·075	·084	......	......	·057
·080	·060	·039	·016	·003	·000	·012	·026	·046	·071	·081	......	......	·050
·093	·070	·045	·018	·000	·002	·010	·035	·057	·072	·084	......	......	·057
·354	·259	·157	·061	·005	·005	·048	·134	·208	·283	·322	......	......	·214
·088	·065	·039	·015	·001	·001	·012	·033	·052	·071	·081	......	......	·053
·087	·064	·038	·014	·000	·000	·011	·032	·051	·070	·080	......	......	·052

Singapore, Eastern Archipelago.

·086	·061	·036	·012	·000	·002	·016	·043	·059	·069	·076	......	......	·054
·082	·062	·038	·013	·001	·000	·010	·026	·045	·064	·071	......	......	·050
·084	·061	·037	·012	·000	·001	·013	·034	·052	·066	·073	......	......	·052

Table D.

Variation of the Barometer, corrected to 32°, at

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
November ......1846...	·080	·066	·050	·045	·047	·053	·070	·091	·112	·114	·106
December	·081	·066	·055	·046	·046	·053	·068	·090	·119	·129	·122
January ....1847...	·066	·050	·041	·051	·055	·067	·082	·104	·117	·118	·111
February	·092	·081	·070	·046	·044	·046	·060	·079	·099	·103	·097
Sums	·319	·263	·216	·188	·192	·219	·280	·364	·447	·464	·436
Means	·080	·066	·054	·047	·048	·055	·070	·091	·112	·116	·109
Variation	·078	·064	·052	·045	·046	·053	·068	·089	·110	·114	·107

Variation of the Barometer, corrected to 32°, at

March ....1847...	......	......	......	·051	·055	·059	·073	·095	·111	·121	·114
April	......	......	......	·054	·054	·054	·062	·080	·099	·103	·101
May	......	......	......	·040	·048	·056	·067	·080	·100	·109	·101
June	......	......	......	·047	·049	·054	·066	·082	·098	·104	·100
Sums	......	......	......	·192	·206	·223	·268	·337	·408	·437	·416
Means	......	......	......	·038	·041	·056	·067	·084	·102	·109	·104
Variation	......	......	......	·037	·040	·055	·066	·083	·101	·108	·103

Variation of the Gaseous Pressure at

Moulmein	......	......	......	·039	·035	·066	·074	·047	·010	·017	·023
Madras	......	......	......	·062	·074	·093	·110	·106	·131	·139	·146
Nicobar	......	......	......	·187	·177	·180	·182	·166	·108	·115	·078
Sambooanga	......	......	......	·227	·230	·224	·245	·198	·147	·108	·124
Penang	......	......	......	·176	·178	·199	·213	·206	·190	·133	·070
Pulo Dinding............	......	......	......	·244	·262	·270	·285	·257	·231	·151	·128
Sarawak..................	·140	·134	·124	·122	·120	·131	·150	·156	·148	·127	·112
Keemah	......	......	......	·232	·240	·253	·278	·230	·188	·133	·094
Pulo Peesang............	......	......	......	......	·131	·139	·147	·151	·163	·130	·096
Singapore	......	......	......	·054	·059	·070	·096	·122	·134	·128	·120
Carimon..................	......	......	......	......	......	·141	·151	·144	·140	·129	·129
Padang	......	......	......	·178	·182	·192	·208	·205	·172	·123	·123
Bencoolen	......	......	......	·159	·167	·169	·175	·122	·113	·103	·090
Batavia, Winter.........	·106	·095	·088	·085	·090	·103	·119	·127	·124	·118	·112
Batavia, Spring.........	......	......	......	·085	·102	·117	·133	·129	·122	·112	·110
Cocos......................	......	......	......	·081	·078	·085	·099	·112	·113	·097	·080

Variation of the Gaseous Pressure at

June ....1846...	·142	·142	·128	·125	·126	·135	·154	·162	·148	·121	·114
July	·143	·134	·128	·129	·126	·134	·151	·159	·154	·129	·109
August	·148	·137	·128	·125	·120	·137	·156	·159	·154	·144	·126
Means	·144	·138	·128	·126	·124	·135	·154	·160	·152	·131	·116
Variation	·140	·134	·124	·122	·120	·131	·150	·156	·148	·127	·112

Table D.

Batavia in Java, Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
·089	·065	·040	·017	·000	·008	·021	·041	·066	·088	·104	·103	·097	·065
·101	·067	·043	·017	·000	·001	·014	·036	·055	·090	·107	·110	·106	·067
·097	·077	·050	·024	·008	·000	·014	·032	·051	·061	·071	·079	·074	·063
·085	·065	·038	·017	·002	·000	·007	·025	·043	·060	·077	·115	·111	·058
·372	·274	·171	·075	·010	·009	·056	·134	·215	·299	·359	·407	·388	·253
·093	·068	·043	·019	·003	·002	·014	·034	·054	·075	·090	·102	·097	·063
·091	·066	·041	·017	·001	·000	·012	·032	·052	·073	·088	·100	·095	·061

Batavia in Java, Eastern Archipelago.

·102	·079	·055	·027	·004	·000	·009	·028	·040	·049	·062	......	......	·061
·086	·060	·039	·016	·000	·002	·011	·028	·036	·049	·060	......	......	·052
·085	·064	·044	·022	·001	·000	·012	·028	·041	·051	·062	......	......	·053
·082	·060	·035	·015	·000	·007	·011	·023	·040	·052	·060	......	......	·053
·355	·263	·173	·080	·005	·009	·043	·107	·157	·201	·244	......	......	·219
·089	·066	·043	·020	·001	·002	·011	·027	·039	·050	·061	......	......	·055
·088	·065	·042	·019	·000	·001	·010	·026	·038	·049	·060	......	......	·054

various Stations in the Eastern Archipelago.

·025	·008	·015	·044	·011	·002	·003	·005	·001	·000	·016	......	......	·023
·147	·136	·117	·093	·050	·010	·019	·019	·000	·008	·022	......	......	·079
·083	·061	·006	·027	·000	·000	·017	·051	·095	·112	·150	......	......	·094
·144	·094	·069	·008	·009	·000	·053	·086	·126	·161	·187	......	......	·130
·053	·065	·072	·056	·032	·000	·053	·080	·092	·117	·144	......	......	·112
·102	·141	·077	·085	·000	·087	·111	·164	·180	·212	·204	......	......	·168
·099	·074	·042	·022	·002	·000	·006	·029	·050	·081	·113	·133	·143	·096
·046	·000	·076	·045	·054	·068	·079	·110	·146	·182	·209	......	......	·146
·066	·056	·020	·020	·020	·000	·027	·034	·067	·090	·109	......	......	·080
·100	·065	·031	·016	·000	·005	·025	·036	·046	·063	·072	......	......	·066
·103	·093	·061	·000	·014	·006	·025	·052	·078	·114	......	......	......	·087
·089	·051	·020	·003	·000	·005	·030	·071	·101	·140	·155	......	......	·111
·073	·041	·020	·000	·026	·026	·036	·075	·119	·147	·158	......	......	·096
·091	·066	·038	·015	·000	·008	·018	·040	·057	·079	·098	·107	·110	·078
·092	·068	·044	·014	·000	·003	·016	·035	·052	·066	·088	......	......	·075
·040	·018	·014	·000	·011	·026	·056	·075	·093	·120	·123	......	......	·070

Sarawak in Borneo.

·100	·065	·039	·024	·000	·003	·023	·026	·051	·083	·114	·129	·143	·098
·100	·085	·063	·043	·018	·000	·017	·007	·047	·081	·117	·136	·144	·101
·108	·084	·041	·012	·005	·009	·000	·007	·065	·091	·121	·147	·154	·100
·103	·078	·046	·026	·006	·004	·010	·013	·054	·085	·117	·137	·147	·100
·099	·074	·042	·022	·002	·000	·006	·009	·050	·081	·113	·133	·143	·096

Table D.

Variation of the Gaseous

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
October.........1847...	......	......	......	·166	·172	·188	·208	·189	·166	·114	·135
November	......	......	.....	·177	·180	·190	·208	·203	·172	·140	·133
December	......	......	......	·171	·173	·180	·191	·192	·147	·089	·090
January ....1848...	......	......	......	·214	·218	·228	·242	·253	·219	·164	·151
Sums	......	......	......	·728	·743	·786	·849	·837	·704	·507	·509
Means	......	......	......	·182	·186	·196	·212	·209	·176	·127	·127
Variation	......	......	......	·178	·182	·192	·208	·205	·172	·123	·123

Variation of the Gaseous

November ......1848...	......	......	......	·058	·067	·082	·098	·134	·141	·136	·124
December	......	......	......	·050	·052	·057	·095	·111	·127	·121	·116
Means and Variation .	......	......	......	·054	·059	·070	·096	·122	·134	·128	·120

Variation of the Gaseous

November ......1846...	·126	·116	·107	·105	·109	·121	·138	·137	·138	·129	·132
December	·109	·098	·087	·081	·085	·098	·116	·122	·124	·120	·116
January.........1847...	·088	·075	·073	·090	·098	·118	·128	·145	·136	·131	·116
February	·107	·094	·091	·070	·073	·080	·100	·109	·102	·098	·088
Sums	·430	·383	·358	·346	·365	·417	·482	·513	·500	·478	·452
Means	·107	·096	·089	·086	·091	·104	·120	·128	·125	·119	·113
Variation	·106	·095	·088	·085	·090	·103	·119	·127	·124	·118	·112

Variation of the Gaseous

March ....1847...	......	......	......	·091	·104	·115	·134	·136	·131	·135	·126
April	......	......	......	·086	·106	·119	·127	·120	·116	·095	·093
May	......	......	......	·093	·115	·131	·154	·140	·130	·125	·112
June	......	......	......	·076	·088	·107	·122	·124	·115	·098	·112
Sums	......	......	......	·346	·413	·472	·537	·520	·492	·453	·443
Means	......	......	......	·086	·103	·118	·134	·130	·123	·113	·111
Variation	......	......	......	·085	·102	·117	·133	·129	·122	·112	·110

TABLE D.

Pressure at Padang in Sumatra, Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	.n.	in.
·092	·059	·026	·000	·005	·006	·015	·061	·097	·137	·145	......	......	·106
·110	·054	·031	·004	·000	·009	·043	·081	·097	·135	·154	......	......	·115
·063	·041	·005	·000	·012	·019	·039	·062	·099	·150	·159	......	......	·106
·107	·068	·031	·026	·000	·003	·038	·098	·128	·153	·179	......	......	·135
·372	·222	·093	·030	·017	·037	·135	·302	·421	·575	·637	......	......	·462
·093	·055	·024	·007	·004	·009	·034	·075	·105	·144	·159	......	......	·115
·089	·051	·020	·003	·000	·005	·030	·071	·101	·140	·155	......	......	·111

Pressure Vapour at Singapore.

·101	·071	·033	·004	·000	·003	·026	·044	·053	·068	·074	......	......	·071
·098	·060	·060	·028	·000	·008	·023	·028	·038	·059	·070	......	......	·062
·100	·065	·031	·016	·000	·005	·025	·036	·046	·063	·072	......	......	·066

Pressure at Batavia.—Winter.

·104	·065	·054	·024	·000	·021	·025	·049	·079	·102	·126	·124	·129	·094
·087	·060	·031	·010	·000	·012	·029	·048	·061	·097	·117	·117	·122	·081
·104	·085	·048	·024	·005	·000	·014	·044	·057	·063	·084	·084	·086	·080
·074	·060	·025	·007	·000	·003	·007	·024	·034	·060	·069	·108	·109	·063
·369	·270	·158	·065	·005	·036	·075	·165	·231	·322	·396	·433	·446	·318
·092	·067	·039	·016	·001	·009	·019	·041	·058	·080	·099	·108	·111	·079
·091	·066	·038	·015	·000	·008	·018	·040	·057	·079	·098	·107	·110	·078

Pressure at Batavia.—Spring.

·111	·086	·062	·022	·000	·000	·021	·042	·061	·072	·103	......	......	·083
·076	·051	·035	·007	·000	·008	·021	·043	·060	·075	·103	......	......	·073
·088	·075	·048	·018	·003	·000	·018	·039	·045	·063	·080	......	......	·079
·097	·064	·036	·014	·000	·010	·009	·019	·045	·059	·072	......	......	·068
·372	·276	·181	·061	·003	·018	·069	·143	·211	·269	·358	......	......	·303
·093	·069	·045	·015	·001	·004	·017	·036	·053	·067	·089	......	......	·076
·092	·068	·044	·014	·000	·003	·016	·035	·052	·066	·088	......	......	·075

Table D.

Observatory at Moulmein.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Portable Barometer, 28 English											
Mean of 7 days	......	......	......	1·863	1·858	1·866	1·876	1·895	1·938	1·965	1·986
Barom. corr. to 32°...	......	......	......	1·755	1·750	1·759	1·769	1·783	1·808	1·826	1·837
Gaseous pressure ...	......	......	......	0·929	0·925	0·956	0·964	0·937	0·900	0·907	0·913

Observatory at Madras.—Hourly observations

Portable Barometer, 28 English											
Mean of 34 days ...	......	......	......	1·780	1·779	1·783	1·787	1·804	1·830	1·852	1·857
Barom. corr. to 32°...	......	......	......	1·668	1·667	1·672	1·677	1·692	1·709	1·720	1·718
Gaseous pressure ...	......	......	......	0·858	0·870	0·889	0·906	0·902	0·927	0·935	0·942

Observatory at Car Nicobar.—Hourly observations

Portable Barometer, 28 English											
Mean of 5 days	......	......	......	2·017	2·019	2·020	2·022	2·040	2·074	2·101	2·122
Barom. corr. to 32°...	......	......	......	1·918	1·920	1·921	1·922	1·938	1·962	1·981	1·994
Gaseous pressure ...	......	......	......	1·168	1·158	1·161	1·163	1·147	1·089	1·096	1·059

Observatory at Sambooanga.—Hourly observations

Standard Barometer, 28 English											
Mean of 6 days	......	......	......	1·957	1·960	1·967	1·976	2·004	2·035	2·051	2·053
Barom. corr. to 32°...	......	......	......	1·837	1·841	1·848	1·857	1·877	1·895	1·903	1·902
Gaseous pressure ...	......	......	......	1·077	1·080	1·074	1·095	1·048	0·997	0·958	0·974

Observatory at Penang.—Hourly observations

Portable Barometer, 28 English											
Mean of 3 days	......	......	......	1·986	1·981	1·983	1·991	2·007	2·031	2·055	2·057
Barom. corr. to 32°...	......	......	......	1·876	1·873	1·878	1·886	1·900	1·921	1·937	1·931
Gaseous pressure ...	......	......	......	1·067	1·069	1·090	1·104	1·097	1·081	1·024	0·961

Observatory at Pulo Dinding.—Hourly observations

Portable Barometer, 28 English											
Mean of 2 days	......	......	......	2·099	2·092	2·091	2·093	2·096	2·117	2·142	2·165
Barom. corr. to 32°...	......	......	......	1·992	1·988	1·989	1·993	1·996	2·010	2·024	2·036
Gaseous pressure ...	......	......	......	1·212	1·230	1·238	1·253	1·225	1·199	1·119	1·096

Observatory at Sarawak.—Hourly observations

Standard Barometer, 28 English											
Mean of 26 days ...	2·018	2·005	1·993	1·985	1·980	1·985	1·994	2·012	2·028	2·040	2·044
Barom. corr. to 32°...	1·891	1·888	1·869	1·861	1·856	1·861	1·872	1·890	1·904	1·910	1·909
Gaseous pressure ...	1·001	1·001	0·987	0·984	0·985	0·994	1·013	1·021	1·007	0·980	0·973

Table D,

made during the Month of April, 1849.

23.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
inches + the numbers in the Table.												
1·987	1·981	1·961	1·929	1·889	1·870	1·861	1·847	1·846	1·853	1·862		
1·827	1·815	1·793	1·761	1·725	1·710	1·706	1·708	1·719	1·732	1·743		
0·915	0·898	0·905	0·934	0·901	0·892	0·893	0·895	0·891	0·890	0·906		

made during the Months of August and September, 1849.

inches + the numbers in the Table.												
1·853	1·846	1·834	1·819	1·801	1·788	1·781	1·781	1·786	1·797	1·808		
1·709	1·699	1·685	1·670	1·656	1·647	1·645	1·652	1·662	1·675	1·688		
0·943	0·932	0·913	0·889	0·846	0·806	0·815	0·815	0·796	0·804	0·818		

made during the Month of February, 1849.

inches + the numbers in the Table.												
2·117	2·102	2·075	2·050	2·029	2·026	2·023	2·023	2·030	2·038	2·047		
1·983	1·967	1·939	1·917	1·898	1·897	1·896	1·904	1·917	1·928	1·940		
1·064	1·042	0·987	1·008	0·981	0·981	0·998	1·032	1·076	1·093	1·131		

made during the Month of May, 1848.

inches + the numbers in the Table.												
2·039	2·026	2·012	1·994	1·979	1·968	1·978	1·988	2·000	2·009	2·019		
1·891	1·875	1·856	1·837	1·820	1·812	1·827	1·842	1·860	1·871	1·887		
0·994	0·944	0·919	0·858	0·859	0·850	0·903	0·936	0·976	1·011	1·037		

made during the Month of January, 1849.

inches + the numbers in the Table.												
2·062	2·051	2·030	2·004	1·971	1·959	1·975	1·974	1·976	1·984	1·993		
1·928	1·915	1·896	1·870	1·836	1·825	1·844	1·848	1·856	1·866	1·878		
0·944	0·956	0·963	0·947	0·923	0·891	0·944	0·971	0·983	1·008	1·035		

made during the Month of January, 1849.

inches + the numbers in the Table.												
2·177	2·173	2·160	2·124	2·098	2·087	2·079	2·075	2·073	2·076	2·086		
2·036	2·025	2·012	1·983	1·959	1·956	1·955	1·956	1·961	1·965	1·976		
1·070	1·109	1·045	1·053	0·968	1·055	1·079	1·132	1·148	1·180	1·172		

made during the Month of June, 1846.

inches + the numbers in the Table.												
2·032	2·015	1·994	1·970	1·953	1·951	1·955	1·965	1·978	1·995	2·011	2·019	2·020
1·892	1·872	1·848	1·823	1·807	1·808	1·815	1·827	1·846	1·865	1·881	1·892	1·893
0·959	0·924	0·898	0·883	0·859	0·862	0·882	0·885	0·910	0·942	0·973	0·988	1·002

TABLE D.

Observatory at Sarawak.—Hourly observations

Standard Barometer, 28 English

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Mean of 27 days ...	2·013	1·998	1·983	1·974	1·969	1·972	1·983	1·998	2·015	2·027	2·029
Barom. corr. to 32°...	1·888	1·874	1·859	1·852	1·847	1·850	1·861	1·878	1·893	1·900	1·899
Gaseous pressure ...	1·013	1·004	0·998	0·999	0·996	1·004	1·021	1·029	1·024	0·999	0·979

Observatory at Sarawak.—Hourly observations

Standard Barometer, 28 English

Mean of 19 days ...	2·034	2·017	2·000	1·991	1·984	1·990	2·003	2·017	2·035	2·051	2·053
Barom. corr. to 32°...	1·910	1·894	1·878	1·869	1·862	1·870	1·884	1·898	1·913	1·927	1·923
Gaseous pressure ...	1·051	1·040	1·031	1·028	1·023	1·040	1·059	1·062	1·057	1·047	1·029

Observatory at Keemah.—Hourly observations

Standard Barometer, 28 English

Mean of 10 days ...	......	......	......	1·980	1·981	1·986	1·994	2·016	2·049	2·060	2·068
Barom. corr. to 32°...	......	......	......	1·861	1·865	1·870	1·878	1·896	1·914	1·917	1·917
Gaseous pressure ...	......	......	......	1·096	1·104	1·117	1·142	1·094	1·052	0·997	0·958

Observatory at Pulo Peesang.—Hourly observations

Standard Barometer, 28 English

Mean of 5 days......	......	......	......	......	2·066	2·064	2·074	2·100	2·125	2·137	2·162
Barom. corr. to 32°...	......	......	......	......	1·962	1·961	1·971	1·993	2·013	2·016	2·021
Gaseous pressure ...	......	......	......	......	1·104	1·112	1·120	1·124	1·136	1·103	1·069

Observatory at Singapore.—Hourly observations

Standard Barometer, 28 English

Mean of 16 days ...	......	......	......	2·026	2·029	2·041	2·053	2·075	2·092	2·098	2·097
Barom. corr. to 32°...	......	......	......	1·891	1·894	1·906	1·918	1·943	1·960	1·963	1·959
Gaseous pressure ...	......	......	......	1·028	1·037	1·052	1·068	1·104	1·111	1·106	1·094

Observatory at Singapore.—Hourly observations

Standard Barometer, 28 English

Mean of 14 days ...	......	......	......	2·017	2·017	2·022	2·036	2·053	2·073	2·083	2·082
Barom. corr. to 32°...	......	......	......	1·887	1·887	1·892	1·908	1·926	1·945	1·952	1·947
Gaseous pressure ...	......	......	......	1·046	1·048	1·053	1·091	1·107	1·123	1·117	1·112

Observatory at Carimon Island.—Hourly observations

Standard Barometer, 28 English

Mean of 6 days......	......	......	......	......	......	2·075	2·089	2·116	2·146	2·152	2·153
Barom. corr. to 32°...	......	......	......	......	......	1·968	1·982	2·003	2·018	2·021	2·020
Gaseous pressure ...	......	......	......	......	......	1·125	1·235	1·128	1·124	1·113	1·113

Table D.

made during the Month of July, 1846.

23.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
inches + the numbers in the Table.												
2·018	2·003	1·982	1·960	1·944	1·937	1·939	1·946	1·961	1·979	2·003	2·018	2·017
1·883	1·863	1·839	1·817	1·801	1·797	1·799	1·810	1·829	1·849	1·876	1·891	1·890
0·970	0·955	0·933	0·913	0·888	0·870	0·887	0·877	0·917	0·951	0·987	1·006	1·014

made during the Month of August, 1846.

inches + the numbers in the Table.												
2·044	2·026	2·000	1·972	1·953	1·949	1·953	1·969	1·997	2·011	2·036	2·048	2·049
1·909	1·886	1·856	1·826	1·807	1·808	1·815	1·834	1·867	1·884	1·909	1·923	1·925
1·011	0·987	0·944	0·915	0·908	0·912	0·903	0·910	0·968	0·994	1·024	1·050	1·057

made during the Month of June, 1848.

inches + the numbers in the Table.												
2·062	2·052	2·028	2·001	1·984	1·976	1·981	1·991	2·006	2·018	2·030		
1·903	1·891	1·869	1·850	1·838	1·830	1·840	1·853	1·874	1·888	1·905		
0·910	0·864	0·940	0·909	0·918	0·932	0·943	0·974	1·010	1·046	1·073		

made during the Month of January, 1846.

inches + the numbers in the Table.												
2·124	2·097	2·074	2·052	2·030	2·031	2·030	2·037	2·047	2·062	2·072		
1·988	1·957	1·935	1·919	1·906	1·905	1·914	1·930	1·940	1·954	1·966		
1·039	1·029	0·993	0·993	0·993	0·973	1·000	1·037	1·040	1·063	1·082		

made during the Month of November, 1848.

inches + the numbers in the Table.												
2·081	2·058	2·033	2·009	1·997	1·998	2·011	2·038	2·054	2·064	2·068		
1·943	1·918	1·893	1·869	1·857	1·859	1·873	1·900	1·916	1·926	1·933		
1·071	1·041	1·003	0·974	0·970	0·973	0·996	1·014	1·023	1·038	1·044		

made during the Month of December, 1848.

inches + the numbers in the Table.												
2·069	2·050	2·027	2·002	1·989	1·987	1·997	2·010	2·029	2·048	2·055		
1·934	1·914	1·890	1·865	1·853	1·852	1·862	1·878	1·897	1·916	1·923		
1·094	1·056	1·026	1·024	0·996	1·004	1·019	1·024	1·034	1·055	1·066		

made during the Month of January, 1846.

inches + the numbers in the Table.												
2·143	2·124	2·105	2·058	2·046	2·039	2·043	2·053	2·052	2·064			
2·009	1·985	1·965	1·917	1·907	1·903	1·908	1·930	1·935	1·952			
1·087	1·077	1·045	0·954	0·998	0·990	1·009	1·136	1·062	1·098			

TABLE D.

Observatory at Padang.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Standard Barometer, 28 English											
Mean of 13 days ...	......	......	......	2·004	2·006	2·013	2·027	2·050	2·080	2·098	2·111
Barom. corr. to 32°...	......	......	......	1·890	1·892	1·899	1·913	1·934	1·956	1·960	1·965
Gaseous pressure ...	......	......	......	1·143	1·149	1·165	1·185	1·166	1·143	1·091	1·112

Observatory at Padang.—Hourly observations

Standard Barometer, 28 English											
Mean of 26 days ...	......	......	......	2·004	2·003	2·009	2·023	2·048	2·077	2·096	2·100
Barom. corr. to 32°...	......	......	......	1·888	1·887	1·895	1·909	1·932	1·953	1·958	1·954
Gaseous pressure ...	......	......	......	1·131	1·134	1·144	1·162	1·157	1·126	1·094	1·087

Observatory at Padang.—Hourly observations

Standard Barometer, 28 English											
Mean of 26 days ...	......	......	......	1·970	1·967	1·972	1·983	2·006	2·031	2·049	2·055
Barom. corr. to 32°...	......	......	......	1·857	1·851	1·856	1·867	1·890	1·907	1·914	1·909
Gaseous pressure ...	......	......	......	1·108	1·110	1·117	1·128	1·129	1·084	1·026	1·027

Observatory at Pedang.—Hourly observations

Standard Barometer, 28 English											
Mean of 13 days ...	......	......	......	1·985	1·981	1·986	2·004	2·027	2·052	2·068	2·070
Barom. corr. to 32°...	......	......	......	1·869	1·865	1·870	1·888	1·911	1·928	1·933	1·927
Gaseous pressure ...	......	......	......	1·102	1·106	1·116	1·130	1·141	1·107	1·052	1·039

Observatory at Poolo Bay.—Hourly observations

Portable Barometer, 28 English											
Mean of 5 days	......	......	......	1·954	1·952	1·948	1·954	1·962	1·990	2·010	2·015
Barom. corr. to 32°...	......	......	......	1·855	1·855	1·851	1·857	1·859	1·880	1·892	1·889
Gaseous pressure ...	......	......	......	1·035	1·043	1·045	1·051	0·998	0·989	0·979	0·966

Observatory at Batavia.—Hourly observations

Standard Barometer, 28 English											
Mean of 19 days ...	2·000	1·983	1·967	1·961	1·962	1·968	1·985	2·006	2·032	2·042	2·039
Barom. corr. to 32°...	1·873	1·859	1·843	1·838	1·840	1·846	1·863	1·884	1·905	1·907	1·899
Gaseous pressure ...	1·023	1·013	1·004	1·002	1·006	1·018	1·035	1·034	1·035	1·026	1·029

Observatory at Batavia.—Hourly observations

Standard Barometer, 28 English											
Mean of 26 days ...	1·999	1·984	1·973	1·963	1·962	1·969	1·984	2·007	2·040	2·058	2·056
Barom. corr. to 32°...	1·875	1·860	1·849	1·840	1·840	1·847	1·862	1·884	1·913	1·923	1·916
Gaseous pressure ...	1·025	1·014	1·003	0·997	1·001	1·014	1·032	1·038	1·040	1·036	1·032

Table D.

made during the Month of October, 1847.

23.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
inches +the numbers in the Table.												
2·103	2·080	2·051	2·027	2·017	2·009	2·015	2·031	2·039	2·050	2·056	......	......
1·949	1·924	1·895	1·871	1·863	1·861	1·872	1·896	1·909	1·926	1·934	......	......
1·069	1·036	1·003	0·977	0·982	0·983	0·992	1·038	1·074	1·114	1·122	......	......

made during the Month of November, 1847.

inches +the numbers in the Table.												
2·091	2·069	2·045	2·020	2·001	1·998	2·005	2·020	2·034	2·049	2·055		
1·940	1·913	1·886	1·864	1·847	1·850	1·862	1·885	1·904	1·922	1·931		
1·064	1·008	0·985	0·958	0·954	0·963	0·997	1·035	1·051	1·089	1·108		

made during the Month of December, 1847.

inches +the numbers in the Table.												
2·050	2·038	2·019	1·996	1·978	1·970	1·974	1·983	1·995	2·014	2·022		
1·899	1·879	1·858	1·835	1·822	1·819	1·831	1·845	1·865	1·890	1·900		
1·000	0·978	0·942	0·937	0·949	0·956	0·976	0·999	1·036	1·087	1·096		

made during the Month of January, 1848.

inches +the numbers in the Table.												
2·065	2·047	2·027	2·000	1·980	1·977	1·979	1·996	2·010	2·020	2·029		
1·914	1·891	1·866	1·839	1·821	1·823	1·831	1·856	1·878	1·893	1·905		
0·995	0·956	0·919	0·914	0·888	0·891	0·926	0·986	1·016	1·041	1·067		

made during the Months of August and September, 1847.

inches +the numbers in the Table.												
2·006	1·994	1·982	1·960	1·948	1·955	1·958	1·960	1·970	1·975	1·980	......	......
1·878	1·863	1·853	1·836	1·827	1·835	1·840	1·848	1·860	1·870	1·877	......	......
0·949	0·917	0·896	0·876	0·902	0·902	0·912	0·951	0·995	1·023	1·034	......	......

made during the Month of November, 1846.

inches +the numbers in the Table.												
2·028	2·007	1·983	1·959	1·941	1·947	1·955	1·972	1·994	2·013	2·027	2·026	2·017
1·882	1·858	1·833	1·810	1·793	1·801	1·814	1·834	1·859	1·881	1·897	1·896	1·890
1·001	0·962	0·951	0·921	0·897	0·918	0·922	0·946	0·969	0·999	1·023	1·021	1·026

made during the Month of December, 1846.

inches +the numbers in the Table.												
2·041	2·007	1·984	1·957	1·940	1·938	1·948	1·965	1·981	2·014	2·031	2·031	2·027
1·895	1·861	1·837	1·811	1·794	1·795	1·808	1·830	1·849	1·884	1·901	1·904	1·900
1·003	0·976	0·947	0·926	0·916	0·928	0·945	0·964	0·977	1·013	1·033	1·033	1·038

Table D.

Observatory at Batavia.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Standard Barometer, 28 English											
Mean of 25 days ...	1·997	1·979	1·969	1·977	1·981	1·992	2·007	2·029	2·045	2·052	2·050
Barom. corr. to 32°...	1·870	1·854	1·845	1·855	1·859	1·871	1·886	1·908	1·921	1·922	1·915
Gaseous pressure ...	1·021	1·008	1·006	1·023	1·031	1·051	1·061	1·078	1·069	1·064	1·049

Observatory at Batavia.—Hourly observations

Standard Barometer, 28 English											
Mean of 24 days ...	2·018	2·006	1·994	1·970	1·968	1·969	1·982	2·001	2·023	2·033	2·032
Barom. corr. to 32°...	1·892	1·881	1·870	1·846	1·844	1·846	1·860	1·879	1·899	1·903	1·897
Gaseous pressure ...	1·028	1·015	1·012	0·991	0·994	1·001	1·021	1·030	1·023	1·019	1·009

Observatory at Batavia.—Hourly observations

Standard Barometer, 28 English											
Mean of 27 days ...	......	......	......	1·993	1·994	1·998	2·012	2·034	2·053	2·068	2·067
Barom. corr. to 32°...	......	......	......	1·866	1·870	1·874	1·888	1·910	1·926	1·936	1·929
Gaseous pressure ...	......	......	......	0·996	1·009	1·020	1·039	1·041	1·036	1·040	1·031

Observatory at Batavia.—Hourly observations

Standard Barometer, 28 English											
Mean of 26 days ...	......	......	......	1·999	1·998	1·997	2·004	2·024	2·046	2·058	2·061
Barom. corr. to 32°...	......	......	......	1·874	1·874	1·874	1·882	1·900	1·919	1·923	1·921
Gaseous pressure ...	......	......	......	1·008	1·028	1·041	1·049	1·042	1·038	1·017	1·015

Observatory at Batavia.—Hourly observations

Standard Barometer, 28 English											
Mean of 26 days ...	......	......	......	1·983	1·989	1·995	2·005	2·021	2·046	2·066	2·062
Barom. corr. to 32°...	......	......	......	1·859	1·867	1·875	1·886	1·899	1·919	1·928	1·920
Gaseous pressure ...	......	......	......	1·027	1·049	1·065	1·088	1·074	1·064	1·059	1·046

Observatory at Batavia.—Hourly observations

Standard Barometer, 28 English											
Mean of 26 days ...	......	......	......	1·984	1·983	1·988	1·997	2·016	2·037	2·054	2·056
Barom. corr. to 32°...	......	......	......	1·862	1·864	1·869	1·881	1·897	1·913	1·919	1·915
Gaseous pressure ...	......	......	......	1·058	1·070	1·089	1·104	1·106	1·097	1·080	1·094

Observatory at Cocos Island.—Hourly observations

Standard Barometer, 28 English											
Mean of 27 days ...	......	......	......	2·059	2·057	2·064	2·077	2·094	2·113	2·129	2·131
Barom. corr. to 32°...	......	......	......	1·935	1·933	1·940	1·953	1·970	1·986	1·997	1·993
Gaseous pressure ...	......	......	......	1·164	1·161	1·168	1·182	1·195	1·196	1·180	1·163

Table D.

23.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
made during the Month of January, 1847.												
inches + the numbers in the Table.												
2·040	2·022	1·998	1·974	1·958	1·950	1·961	1·976	1·991	2·000	2·007	2·014	2·008
1·901	1·881	1·854	1·828	1·812	1·804	1·818	1·836	1·855	1·865	1·875	1·883	1·878
1·037	1·018	0·981	0·957	0·938	0·933	0·947	0·977	0·990	0·996	1·017	1·017	1·019
made during the Month of February, 1847.												
inches + the numbers in the Table.												
2·023	2·005	1·981	1·961	1·945	1·941	1·945	1·960	1·975	1·991	2·007	2·044	2·039
1·885	1·865	1·838	1·817	1·802	1·800	1·807	1·825	1·843	1·860	1·877	1·915	1·911
0·995	0·981	0·946	0·928	0·921	0·924	0·928	0·945	0·955	0·981	0·990	1·029	1·030
made during the Month of March, 1847.												
inches + the numbers in the Table.												
2·058	2·038	2·016	1·989	1·966	1·961	1·968	1·983	1·993	2·000	2·009		
1·917	1·894	1·870	1·842	1·819	1·815	1·824	1·843	1·855	1·864	1·877		
1·016	0·991	0·967	0·927	0·903	0·905	0·926	0·947	0·966	0·977	1·008		
made during the Month of April, 1847.												
inches + the numbers in the Table.												
2·049	2·027	2·007	1·984	1·967	1·968	1·974	1·988	1·994	2·004	2·012		
1·906	1·880	1·859	1·836	1·820	1·822	1·831	1·848	1·856	1·869	1·880		
0·998	0·973	0·957	0·929	0·922	0·930	0·943	0·965	0·982	0·997	1·025		
during the Months of May, 1847.												
inches + the numbers in the Table.												
2·051	2·034	2·014	1·989	1·968	1·966	1·975	1·987	1·996	2·005	2·013		
1·904	1·883	1·863	1·841	1·820	1·819	1·831	1·847	1·860	1·870	1·881		
1·022	1·009	0·982	0·952	0·937	0·934	0·952	0·973	0·979	0·997	1·014		
made during the Month of June, 1847.												
inches + the numbers in the Table.												
2·045	2·026	2·002	1·981	1·966	1·969	1·969	1·977	1·991	2·000	2·007		
1·897	1·875	1·850	1·830	1·815	1·822	1·826	1·838	1·855	1·867	1·875		
1·079	1·046	1·018	0·996	0·982	0·992	0·991	1·001	1·027	1·041	1·054		
made during the Months of August and September, 1848.												
inches + the numbers in the Table.												
2·121	2·103	2·087	2·068	2·055	2·054	2·061	2·072	2·088	2·104	2·115		
1·981	1·960	1·944	1·928	1·917	1·919	1·929	1·942	1·961	1·977	1·988		
1·123	1·101	1·097	1·083	1·094	1·109	1·139	1·158	1·176	1·203	1·206		

Table E.

Diurnal variation of the Standard Thermometer at

Astron. Mean Time.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
Moulmein	......	......	......	0·4	0·5	0·2	0·0	1·7	7·6	11·4	15·4
Madras	......	......	......	1·2	0·8	0·3	0·0	1·2	4·6	8·0	10·5
Nicobar	......	......	......	0·0	0·2	0·2	0·4	1·0	4·3	7·2	10·5
Sambooanga	......	......	......	0·2	0·1	0·1	0·0	3·4	9·1	10·7	11·4
Penang	......	......	......	1·1	0·9	0·1	0·0	0·7	2·1	6·0	10·0
Pulo Dinding	......	......	......	1·9	1·0	0·5	0·0	0·4	2·7	7·4	12·7
Sarawak	1·7	1·4	1·1	0·8	0·5	0·3	0·1	0·0	0·9	2·8	4·7
Keemah	......	......	......	0·9	0·5	0·3	0·0	2·1	8·1	11·0	14·2
Pulo Peesang	......	......	......	0·7	0·0	0·2	1·1	2·5	6·0	10·6	13·7
Singapore	......	......	......	0·9	0·8	0·6	0·3	0·0	0·4	1·1	1·7
Carimon	......	......	......	......	......	0·3	0·0	2·2	5·3	8·6	10·8
Padang	......	......	......	0·6	0·3	0·1	0·0	1·1	5·1	9·7	12·6
Bencoolen	......	......	......	0·5	0·2	0·1	0·0	2·0	4·9	7·7	10·2
Batavia, Winter	1·9	1·6	1·2	0·7	0·5	0·2	0·0	0·5	2·1	4·3	6·2
Batavia, Spring	......	......	......	1·1	0·7	0·2	0·0	0·6	2·6	5·6	7·5
Cocos	......	......	......	0·3	0·1	0·2	0·0	0·4	1·5	3·4	4·8

Observatory at Moulmein.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Noon.
Standard Thermometer.													
Mean of 7 days	......	......	......	77·7	77·5	77·2	77·0	78·7	84·6	88·4	92·4	97·1	99·7
Diurnal variation	......	......	......	0·4	0·5	0·2	0·0	1·7	7·6	11·4	15·4	20·1	22·7

Observatory at Madras.—Hourly observations

Standard Thermometer.													
Mean of 34 days	......	......	......	78·8	78·4	77·9	77·6	78·8	82·2	85·6	88·1	90·2	92·0
Diurnal variation	......	......	......	1·2	0·8	0·3	0·0	1·2	4·6	8·0	10·5	12·6	14·4

Observatory at Car Nicobar.—Hourly observations

Standard Thermometer.													
Mean of 5 days	......	......	......	73·8	74·0	74·0	74·2	74·8	78·1	81·0	84·3	86·6	87·4
Diurnal variation	......	......	......	0·0	0·2	0·2	0·4	1·0	4·3	7·2	10·5	12·8	13·6

Observatory at Sambooanga.—Hourly observations

Standard Thermometer.													
Mean of 6 days	......	......	......	74·9	74·8	74·8	74·7	78·1	83·8	85·4	86·1	84·7	86·5
Diurnal variation	......	......	......	0·2	0·1	0·1	0·0	3·4	9·1	10·7	11·4	10·0	11·8

Table E.

various stations in the Eastern Archipelago.

23.	Noon.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Mean.
20·1	22·7	23·4	23·7	23·2	19·7	17·6	11·5	15·3	17·2	18·2	……	……	11·4
12·6	14·4	15·5	15·2	13·9	12·6	10·4	7·7	6·0	5·0	4·4	……	……	7·6
12·8	13·6	14·3	13·2	12·2	12·1	11·0	7·8	5·7	4·7	3·6	……	……	7·1
10·0	11·8	13·5	14·3	13·9	12·7	10·7	8·7	8·4	6·1	5·0	……	……	7·8
12·4	13·3	12·0	10·8	11·0	9·5	8·2	6·2	4·8	4·0	3·6	……	……	6·2
17·9	19·4	20·6	18·6	16·8	13·0	9·7	6·8	5·1	4·3	3·8	……	……	8·5
6·3	7·8	8·6	8·9	8·6	7·7	6·9	5·7	3·9	3·2	2·8	2·4	2·0	3·7
16·4	17·9	15·3	13·3	12·0	11·1	9·3	7·8	6·2	5·3	4·5	……	……	8·2
14·9	15·0	10·9	8·4	7·6	5·2	3·7	3·2	3·5	2·7	……	……	……	6·1
2·1	2·4	2·6	2·5	2·5	2·3	2·0	1·8	1·7	1·6	1·2	……	……	1·5
13·9	14·4	14·4	15·0	13·1	11·8	9·3	5·8	4·3	3·3	……	……	……	8·3
15·0	16·6	17·5	16·8	15·1	12·8	10·3	7·4	5·4	4·0	3·1	……	……	8·1
11·0	12·4	14·8	10·0	8·9	9·0	7·8	6·1	4·9	3·3	2·6	……	……	6·1
7·6	8·4	9·0	9·1	8·7	8·0	6·9	5·5	4·5	3·9	3·4	3·1	2·5	4·2
9·0	10·1	10·3	10·2	10·1	9·3	8·2	6·6	5·6	4·8	4·1	……	……	5·6
6·4	6·8	6·8	5·8	4·7	3·5	2·4	1·5	1·2	1·0	0·9	……	……	2·6

made during the Month of April, 1849.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.
Standard Thermometer.												
100·4 23·4	100·7 23·7	99·2 22·2	96·7 19·7	94·6 17·6	88·5 11·5	84·5 7·5	82·6 5·6	81·6 4·6	……	……	1679·1	88·4

made during the Months of August and September, 1849.

Standard Thermometer.												
93·1 15·5	92·8 15·2	91·5 13·9	90·2 12·6	88·0 10·4	85·3 7·7	83·6 6·0	82·6 5·0	82·0 4·4	……	……	1618·7	85·2

made during the Month of February, 1849.

Standard Thermometer.												
88·1 14·3	87·0 13·2	86·0 12·2	85·9 12·1	84·8 11·0	81·6 7·8	79·5 5·7	78·5 4·7	77·4 3·6	……	……	1537·0	80·9

made during the Month of May, 1848.

Standard Thermometer.												
88·2 13·5	89·0 14·3	88·6 13·9	87·4 12·7	85·4 10·7	83·4 8·7	81·9 7·2	80·8 6·1	79·7 5·0	……	……	1568·2	82·5

TABLE E.

Observatory at Penang.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	Noon.
Standard Thermometer.													
Mean of 5 days......	......	......	......	76·6	76·4	75·6	75·6	76·2	77·6	81·5	85·5	87·9	88·8
Diurnal variation ...	......	......	......	1·1	0·9	0·1	0·0	0·7	2·1	6·0	10·0	12·4	13·3

Observatory at Pulo Dinding.—Hourly observations

Standard Thermometer.													
Mean of 3 days......	......	......	......	76·0	75·1	74·6	74·1	74·5	76·8	81·5	86·8	92·0	93·5
Diurnal variation ...	......	......	......	1·9	1·0	0·5	0·0	0·4	2·7	7·4	12·7	17·9	19·4

Observatory at Sarawak.—Hourly observations

Standard Thermometer.													
Mean of 26 days ...	77·5	77·2	76·8	76·5	76·3	76·1	75·9	75·9	76·9	78·9	80·9	82·6	83·9
Diurnal variation ...	1·6	1·3	0·9	0·6	0·4	0·2	0·0	0·0	1·0	3·0	5·0	6·7	8·0

Observatory at Sarawak.—Hourly observations

Standard Thermometer.													
Mean of 27 days ...	77·0	76·8	76·4	76·1	75·9	75·7	75·4	75·3	76·1	77·9	79·5	81·0	82·4
Diurnal variation	1·7	1·5	1·1	0·8	0·6	0·4	0·1	0·0	0·8	2·6	4·2	5·7	7·1

Observatory at Sarawak.—Hourly observations

Standard Thermometer.													
Mean of 19 days ...	76·6	76·3	76·0	75·7	75·4	75·2	74·9	74·9	75·8	77·7	79·6	81·4	83·0
Diurnal variation ...	1·7	1·4	1·1	0·8	0·5	0·3	0·0	0·0	0·9	2·8	4·7	6·5	8·1

Observatory at Keemah.—Hourly observations

Standard Thermometer.													
Mean of 10 days ...	......	......	......	74·3	73·9	73·7	73·4	75·5	81·5	84·4	87·6	89·8	91·3
Diurnal variation ...	......	......	......	0·9	0·5	0·3	0·0	2·1	8·1	11·0	14·2	16·4	17·9

Observatory at Pulo Peesang.—Hourly observations

Standard Thermometer.													
Mean of 5 days......	......	......	......	......	75·9	75·2	75·4	76·3	77·7	81·2	85·8	88·9	90·1
Diurnal variation ...	......	......	......	......	0·7	0·0	0·2	1·1	2·5	6·0	10·6	13·7	14·9

Observatory at Singapore.—Hourly observations

Standard Thermometer.													
Mean of 16 days ...	......	......	......	79·3	79·2	79·1	78·9	78·6	78·9	79·4	79·9	80·5	80·7
Diurnal variation ...	......	......	......	0·7	0·6	0·5	0·3	0·0	0·3	0·8	1·3	1·9	2·1

Table E.

made during the Month of January, 1849.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.
Standard Thermometer.												
87·5 12·0	86·3 10·8	86·5 11·0	85·0 9·5	83·7 8·2	81·7 6·2	80·3 4·8	79·5 4·0	79·1 3·6	......	......	1551·2	81·7

made during the Month of January, 1849.

Standard Thermometer.												
94·7 20·6	92·7 18·6	90·9 16·8	87·1 13·0	83·8 9·7	80·9 6·8	79·2 5·1	78·4 4·3	77·9 3·8	......	......	1570·5	82·6

made during the Month of June, 1846.

Standard Thermometer.												
84·6 8·7	84·6 8·7	84·2 8·3	83·5 7·6	82·6 6·7	81·2 5·3	79·9 4·0	79·2 3·3	78·6 2·7	78·2 2·3	77·8 1·9	1909·8	79·6

made during the Month of July, 1846.

Standard Thermometer.												
83·1 7·8	83·5 8·2	83·2 7·9	82·9 7·6	82·0 6·7	81·0 5·7	79·2 3·9	78·6 3·3	78·1 2·8	77·7 2·4	77·3 2·0	1892·1	78·8

made during the Month of August, 1846.

Standard Thermometer.												
84·2 9·3	84·5 9·6	84·3 9·4	82·8 7·9	82·0 7·1	80·8 5·9	78·7 3·8	77·9 3·0	77·6 2·7	77·3 2·4	77·0 2·1	1889·6	78·7

made during the Month of June, 1848.

Standard Thermometer.												
88·7 15·3	86·7 13·3	85·4 12·0	84·5 11·1	82·7 9·3	81·2 7·8	79·6 6·2	78·7 5·3	77·9 4·5	......	......	1550·8	81·5

made during the Month of January, 1846.

Standard Thermometer.												
90·2 15·0	86·1 10·9	83·6 8·4	82·8 7·6	80·4 5·2	78·9 3·7	78·4 3·2	78·7 3·5	77·9 2·7	......	......	1463·5	81·5

made during the Month of November, 1848.

Standard Thermometer.												
80·9 2·3	80·9 2·3	80·8 2·2	80·5 1·9	80·4 1·8	80·3 1·7	80·1 1·5	79·9 1·3	79·5 0·9	......	......	1517·8	79·9

TABLE E.

Observatory at Singapore.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Standard Thermometer.													
Mean of 14 days ...	......	......	......	79·0	78·9	78·7	78·2	78·0	78·5	79·4	80·0	80·3	80·7
Diurnal variation ...	......	......	......	1·0	0·9	0·7	0·2	0·0	0·5	1·4	2·0	2·3	2·7

Observatory at Carimon Island.—Hourly observations

Standard Thermometer.													
Mean of 6 days	......	......	......	......	......	76·7	76·4	78·6	81·7	85·0	87·2	90·3	90·8
Diurnal variation ...	......	......	......	......	......	0·3	0·0	2·3	5·3	8·6	10·8	13·9	14·4

Observatory at Padang.—Hourly observations

Standard Thermometer.													
Mean of 13 days ...	......	......	......	73·0	72·8	72·6	72·4	74·1	78·2	82·6	85·3	87·3	88·7
Diurnal variation ...	......	......	......	0·6	0·4	0·2	0·0	1·7	5·8	10·2	12·9	14·9	16·3

Observatory at Padang.—Hourly observations

Standard Thermometer.													
Mean of 26 days ...	.....	......	......	73·4	73·2	73·0	73·0	74·5	78·5	82·9	85·3	87·5	88·8
Diurnal variation ...	......	......	......	0·4	0·2	0·0	0·0	1·5	5·5	9·9	12·3	14·5	15·8

Observatory at Padang.—Hourly observations

Standard Thermometer.													
Mean of 26 days ...	......	......	......	74·0	73·5	73·3	73·2	74·1	77·8	82·7	86·2	88·6	90·8
Diurnal variation ...	......	......	......	0·8	0·3	0·7	0·0	0·9	4·6	9·5	13·0	15·4	17·6

Observatory at Padang.—Hourly observations

Standard Thermometer.													
Mean of 13 days ...	......	......	......	73·8	73·5	73·3	73·2	73·9	77·7	82·6	85·7	88·6	89·9
Diurnal variation ...	......	......	......	0·6	0·3	0·1	0·0	0·7	4·5	9·4	12·5	15·4	16·7

Observatory at Poolo Bay.—Hourly observations

Standard Thermometer.													
Mean of 5 days ...	......	......	......	73·7	73·4	73·3	73·2	75·2	78·1	80·9	83·4	84·2	85·6
Diurnal variation ...	......	......	......	0·5	0·2	0·1	0·0	2·0	4·9	7·7	10·2	11·0	12·4

Observatory at Batavia.—Hourly observations

Standard Thermometer.													
Mean of 19 days ...	77·7	77·4	76·9	76·6	76·3	76·0	75·7	76·5	78·7	80·9	83·1	84·9	85·8
Diurnal variation ...	2·0	1·7	1·2	0·9	0·6	0·3	0·0	0·8	3·0	5·2	7·4	9·2	10·1

Table E.

made during the Month of December, 1848.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.
Standard Thermometer.												
80·8	80·6	80·7	80·6	80·1	79·8	79·8	79·7	79·4	......	......	1513·2	79·6
2·8	2·6	2·7	2·6	2·1	1·8	1·8	1·7	1·4				

made during the Month of January, 1846.

Standard Thermometer.												
90·8	91·4	89·5	88·2	85·7	82·2	80·7	79·7	......	......	......	1354·9	84·8
14·4	15·0	13·1	11·8	9·3	5·8	4·3	3·3					

made during the Month of October, 1847.

Standard Thermometer.												
88·9	88·5	87·2	84·9	82·1	79·7	77·9	76·4	75·6	......	......	1528·2	80·5
16·5	16·1	14·8	12·5	9·7	7·3	5·5	4·0	3·2				

made during the Month of November, 1847.

Standard Thermometer.												
89·4	88·4	86·9	85·0	82·9	80·2	78·5	77·2	76·3	......	......	1534·9	80·8
16·4	15·4	13·9	12·0	9·9	7·2	5·5	4·2	3·3				

made during the Month of December, 1847.

Standard Thermometer.												
91·5	90·6	88·9	85·7	83·3	80·3	78·2	77·0	75·9	......	......	1545·6	81·3
18·3	17·4	15·7	12·5	10·1	7·1	5·0	3·8	2·7				

made during the Month of January, 1848.

Standard Thermometer.												
92·1	91·5	89·5	87·5	84·8	81·3	79·0	77·4	76·5	......	......	1551·8	81·7
18·9	18·3	16·3	14·3	11·6	8·1	5·8	4·2	3·3				

made during the Months of August and September, 1847.

Standard Thermometer.												
85·0	83·2	82·1	82·2	81·0	79·3	78·1	76·5	75·8	......	......	1504·2	79·3
11·8	10·0	8·9	9·0	7·8	6·1	4·9	3·3	2·6				

made during the Month of November, 1846.

Standard Thermometer.												
86·0	86·0	85·2	84·2	83·0	81·3	80·4	79·7	79·1	78·7	78·3	1928·4	80·3
10·3	10·3	9·5	8·5	7·3	5·6	4·7	4·0	3·4	3·0	2·6		

Table E.

Observatory at Batavia.—Hourly observations

Astron. Mean Time of Station.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	0.
Standard Thermometer.													
Mean of 26 days ...	77·3	77·1	76·8	76·4	76·1	75·9	75·7	76·3	78·3	80·9	83·2	84·4	84·2
Diurnal variation ...	1·6	1·4	1·1	0·7	0·4	0·2	0·0	0·6	2·6	5·2	7·5	8·7	8·5

Observatory at Batavia.—Hourly observations

Standard Thermometer.													
Mean of 25 days ...	78·1	77·7	77·0	76·4	76·0	75·6	75·4	75·8	77·2	79·4	80·9	82·2	83·3
Diurnal variation ...	2·7	2·3	1·6	1·0	0·6	0·2	0·0	0·4	1·8	4·0	5·5	6·8	7·9

Observatory at Batavia.—Hourly observations

Standard Thermometer.													
Mean of 24 days ...	77·5	77·3	77·0	76·6	76·4	76·2	76·1	76·3	77·3	79·1	80·6	82·0	83·2
Diurnal variation ...	1·4	1·2	0·9	0·5	0·3	0·1	0·0	0·2	1·2	3·0	4·5	5·9	7·1

Observatory at Batavia.—Hourly observations

Standard Thermometer.													
Mean of 27 days ...	......	......	......	77·8	77·4	77·0	76·7	77·0	78·3	80·4	82·2	83·6	84·4
Diurnal variation ...	......	......	......	1·1	0·7	0·3	0·0	0·3	1·6	3·7	5·5	6·9	7·7

Observatory at Batavia.—Hourly observations

Standard Thermometer.													
Mean of 26 days ...	......	......	......	77·3	76·7	76·2	76·1	76·7	78·6	81·0	83·1	84·4	85·3
Diurnal variation ...	......	......	......	1·2	0·6	0·1	0·0	0·6	2·5	4·9	7·0	8·3	9·2

Observatory at Batavia.—Hourly observations

Standard Thermometer.													
Mean of 26 days ...	......	......	......	76·3	75·8	75·3	75·1	75·9	78·3	82·2	83·6	85·3	86·7
Diurnal variation ...	......	......	......	1·2	0·7	0·2	0·0	0·8	3·2	7·1	8·5	10·2	11·6

Observatory at Batavia.—Hourly observations

Standard Thermometer.													
Mean of 26 days ...	......	......	......	75·5	75·1	74·7	74·4	75·1	77·4	81·2	83·5	85·2	86·4
Diurnal variation ...	......	......	......	1·1	0·7	0·3	0·0	0·7	3·0	6·8	9·1	10·8	12·0

Observatory at Cocos Island.—Hourly observations

Standard Thermometer.													
Mean of 27 days ...	......	......	......	76·9	76·7	76·8	76·6	77·0	78·1	80·0	81·4	83·0	83·4
Diurnal variation ...	......	......	......	0·3	0·1	0·2	0·0	0·4	1·5	3·4	4·8	6·4	6·8

Table E.

made during the Month of December, 1846.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Sums.	Means.
Standard Thermometer.												
84·8 9·1	84·7 9·0	84·3 8·6	83·7 8·0	82·1 6·4	80·5 4·8	79·7 4·0	79·2 3·5	78·6 2·9	78·2 2·5	77·7 2·0	1916·1	79·8

made during the Month of January, 1847.

Standard Thermometer.												
84·4 9·0	84·7 9·3	84·8 9·4	84·4 9·0	83·8 8·4	82·4 7·0	81·0 5·6	80·4 5·0	80·0 4·6	79·4 4·0	78·8 3·4	1919·1	80·1

made during the Month of February, 1847.

Standard Thermometer.												
83·9 7·8	84·2 8·1	83·7 7·6	82·8 6·7	81·8 5·7	80·7 4·6	80·1 4·0	79·3 3·2	79·0 2·9	78·7 2·6	78·3 2·2	1908·1	79·6

made during the Month of March, 1847.

Standard Thermometer.												
85·0 8·3	85·4 8·7	85·6 8·9	85·0 8·3	84·1 7·4	82·4 5·7	81·5 4·8	80·9 4·2	80·0 3·3	......	......	1544·7	81·3

made during the Month of April, 1847.

Standard Thermometer.												
85·5 9·4	85·5 9·4	85·3 9·2	84·7 8·6	83·5 7·4	82·4 6·3	81·4 5·3	80·5 4·4	79·8 3·7	......	......	1544·0	81·3

made during the month of May, 1847.

Standard Thermometer.												
86·5 11·4	85·8 10·7	85·5 10·4	84·9 9·8	83·8 8·7	82·0 6·9	81·0 5·9	80·2 5·1	79·5 4·4	......	......	1543·7	81·2

made during the Month of June, 1847.

Standard Thermometer.												
86·7 12·3	86·4 12·0	86·2 11·8	84·9 10·5	83·7 9·3	81·9 7·5	80·9 6·5	80·0 5·6	79·6 5·2	......	......	1538·8	81·0

made during the Months of August and September, 1848.

Standard Thermometer.												
83·4 6·8	82·4 5·8	81·3 4·7	80·1 3·5	79·0 2·4	78·1 1·5	77·8 1·2	77·6 1·0	77·5 0·9	......	......	1507·1	79·2

TABLE F.

Observations of Inclination at various Stations in the Eastern Archipelago.

Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.
				Direct.	Reversed.		
				—	—	—	South.
1846.							—
Mar. 18.	Singapore ...	... Madras.	A 1.	8° 48′·6	16° 53′·1	12° 50′·9	
19.			A 1.	8 54·8	16 28·3	12 41·6	
21.			A 1.	8 48·7	16 48·3	12 48·5	
21.			A 1.	8 37	16 38·1	12 37·5	
27.			A 1.	8 16·3	16 58·9	12 37·8	
Apr. 16.			A 1.	8 54·1	16 48·2	12 51·1	
17.			A 1.	9 03·0	16 40·5	12 51·8	
21.			A 1.	8 50·7	16 51·9	12 51·3	
				Mean dip from A 1......			12° 44′·6
Mar. 17.			A 2.	11 13·0	14 36·3	12 54·7	
19.			A 2.	11 31·5	14 13·4	12 52·4	
21.			A 2.	11 28·5	13 51·2	12 39·8	
21.			A 2.	11 31·6	14 16·8	12 54·3	
27.			A 2.	11 19·3	14 08·1	12 44·1	
28.			A 2.	11 03·9	14 12·6	12 38·3	
Apr. 16.			A 2.	10 40 2	13 42·7	12 41·5	
17.			A 2.	11 28·2	14 20·8	12 54·6	
21.			A 2.	11 36·1	13 54·8	12 45·4	
				Mean dip found from A 2			12 47·2
Mar. 21.			A 2 L.	12 29·5	13 06·4	12 48·0	
Apr. 16.			A 2 L.	12 19·4	13 10·5	12 44·9	
17.			A 2 L.	12 04·9	13 47·4	12 56·2	
21.			A 2 L.	12 22·3	13 29·8	12 56·1	
				Mean dip from A 2 L....			12 51·3
				—	+		
Mar. 21.			A 1 L.	25 13·9	0 24·5	12 36·9	
Apr. 16.			A 1 L.	24 56·7	0 12·1	12 22·3	
17.			A 1 L.	24 52·6	0 29·1	12 11·7	
21.			A 1 L.	24 49·7	0 39·4	12 05·1	
			Mean dip from A 1 L.......			12 19·0	
			Add for correction			— 28·0	
			Mean dip with correction...			....	12 47
			Mean dip found at Singapore.........				12 47
	BORNEO.						
May 15.	Sarāwak	... Madras.	A 1.	7 10·3	14 51	11 00·1	
21.			A 1.	7 19·1	14 51·8	11 05 5	
27.			A 1.	7 25·0	15 13·4	11 19·2	
29.			A 1.	7 21	15 01·7	11 11·3	
June 13.			A 1.	7 12·7	15 09·1	11 11·0	
20.			A 1.	7 21·5	15 06·3	11 13·9	
27.			A 1.	7 12·5	15 04·3	11 08·4	
July 2.			A 1.	7 11·2	14 50·0	11 00·6	
6.			A 1.	7 00·7	15 17·4	11 09·0	
			Mean dip at Sarawak from A 1......				11 08·8
May 15.			A 2.	9 29·3	12 21·6	10 55·5	
21.			A 2.	9 51·5	12 35·8	11 13·7	
27.			A 2.	9 52·0	12 32·3	11 12·5	
29.			A 2.	9 58·5	12 31·4	11 15·0	
June 13.			A 2.	10 03	12 44·2	11 23·6	
20.			A 2.	9 58·3	12 28·0	11 13·2	
27.			A 2.	9 27·8	13 10·3	11 19 1	
July 2.			A 2.	9 37·3	12 36·0	11 06·9	
6.			A 2.	9 42	12 29·2	11 05·6	
				Mean dip from A 2......			11 11·6
May 15.			A 2 L.	10 40·8	11 47·1	11 14	
21.			A 2 L.	10 20·6	12 17·3	11 18·9	
27.			A 2 L.	10 01·5	11 56·5	10 59·0	
29.			A 2 L.	10 00·5	11 54·6	10 57·5	
June 13.			A 2 L.	10 11·8	12 11·5	11 11·6	
20.			A 2 L.	10 19·4	12 15·9	11 17·6	
27.			A 2 L.	10 16·1	11 48·1	11 02·1	
July 2.			A 2 L.	10 08·5	12 01·3	11 04·9	
6.			A 2 L.	10 37·6	11 49·9	11 13·7	
				Mean dip from A 2 L....			11 08·8
1846.	BORNEO.						
May 15.	Sarāwak	... Madras.	A 1 L.	23° 23′·6	1° 42′	10° 50′·8	
21.			A 1 L.	23 31·3	1 49·2	10 51·1	
27.			A 1 L.	23 36·2	1 59·1	10 48·5	
29.			A 1 L.	23 22·7	2 19·8	10 31·4	
June 13.			A 1 L.	23 25·7	1 44·6	10 50·5	
			A 1 L.	20 14·2	1 28	10 59·1*	
20.			A 1 L.	20 43·1	1 19	11 00·1	
27.			A 1 L.	20 37·5	1 06	10 51·7	
July 2.			A 1 L.	20 37·5	0 54·5	10 44·6	
6.							
			Mean from A 1 L.			10 49·7	
			Add for correction			— 28·0	
			Mean dip from A 1 L.......			....	11° 17′·7
			Mean dip found at Sarāwak				11 10·9
July 20.	Sambas	...	A 1.	7 21·2	15 15·7	11 18·3	
				7 29·1	15 21·5	11 25·3	
			Mean dip at Sambas from A 1				11 21·8
			A 2.	10 17·4	12 47	11 32·2	
				10 04·3	12 38·4	11 21·4	
			Mean dip at Sambas from A 2				11 26·8
			A 2 L.	10 37·4	12 31·5	11 34·5	
				10 37·1	12 17·7	11 27·5	
			Mean dip at Sambas from A 2 L. ...				11 31
			A 1 L.	20 43·8	1 09·7	10 56·8	
				20 47·3	1 25·9	11 06·6	
			Mean dip from A 1 L.......			11 01·7	
			Add for cor. — 28			28	
			Mean dip from A 1 L.				11 29·7
			Mean dip found at Sambas				11 27
July 26.	Permanket ...	...	A 1.	8 41·0	16 18	12 29·5	
			A 2.	11 08·7	13 47·3	12 28·0	
			A 2 L.	11 47·5	13 21·3	12 34·4	
			A 1 L.	21 43·6	2 37·8	12 38·7†	
				Mean dip at Permanket ...			12 31·8
Aug. 3.	Pantiānak ...	... Madras.	A 1.	10 57·6	18 28·5	14 43·0	
			A 1.	10 41·2	18 29·5	14 35·4	
			A 1.	10 51·2	18 35·4	14 43·3	
				Mean dip from A 1........			14 40·6
			A 2.	13 27·8	15 55·5	14 41·7	
			A 2.	13 12·6	16 16·4	14 44·5	
			A 2.	13 05·1	16 04·7	14 35·0	
				Mean dip from A2		14 40·4	14 40·4
			A 2 L.	13 52·3	15 47·1	14 49·7	
			A 2 L.	13 48	15 29·0	14 38·5	
			A 2 L.	14 04·7	15 27·2	14 46·1	
				Mean dip from A 2 L.			14 44·7
			A 1 L.	23 57·7	4 45·1	14 21·4	
			A 1 L.	23 35·0	4 36·8	14 05·9	
			A 1 L.	23 30·3	4 34·4	14 02·4	
			Mean dip from A 1 L.			14 09·9	
			Add for correction			— 28	
			Mean dip from A 1 L......			....	14 37·9
			Mean dip found at Pantiānak in Borneo........				14 41·3

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* Grinding the needle slightly on a hone.

† Correction —28′ for A 1 L.

TABLE F.

Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.
				Direct.	Reversed.		
				—	—	—	South.
1846.	BORNEO.						—
Aug. 13.	Succadāna ...	...	A 1.	13° 08′·1	20° 47′·4	16° 57′·8	
			A 2.	15 30·8	18 35·2	17 03·0	
			A 2 L.	16 22·7	17 45·2	17 03·9	
			A 1 L.	25 44·2	6 58·6	16 49·4*	
				Mean dip at Succadāna...			16° 58′·4
	JAVA.						
Sept. 14.	Batavia	...	A 1.	23 46·4	30 26·4	27 06·4	
				24 03·7	30 19·5	27 11·6	
				23 51·7	30 07·6	26 59·6	
				Mean dip from A 1.			27 05·7
			A 2.	25 51·3	28 22·2	27 06·7	
				25 47·3	28 09·0	26 58·1	
				25 51·1	28 21·3	27 06·2	
				Mean dip from A 2.			27 03·7
			A 2 L.	26 25·9	27 44·7	27 05·3	
				26 17	27 44·7	27 00·8	
				26 15·7	27 41·2	26 58·2	
				Mean dip from A 2 L. ...			27 01·5
		Madras.	A 1 L.	34 46·6	18 00·6	26 23·6	
				34 49·5	17 51·7	26 20·6	
				34 56·6	18 34·8	26 45·7	
			Mean dip from A 1 L.			26 30	
			Add for correction			28	
			Mean dip corrected for A 1 L.			....	26 58
			Mean dip at Batavia........................				27 03·0
Sept. 29.	Bantam Residency, Ceram.		A 1.	23 55·9	30 19·7	27 07·8	
			A 2.	26 07·3	28 26·2	27 16·7	
			A 2 L.	26 39·8	27 39·2	27 09·5	
			A 1 L.	34 57·3	18 25·0	27 09·1*	
				Mean dip at Ceram			27 11·0
30.	Anjeer	...	A 1.	23 12·6	30 00	26 36·3	
			A 2.	25 17·4	27 30	26 23·7	
			A 2 L.	25 48·5	27 11·4	26 30	
			A 1 L.	34 11·6	17 35·1	26 21·3*	
				Mean dip at Anjeer			26 28·8
Oct. 2.	Cheringin ...	...	A 1.	24 24·0	30 37·8	27 30·9	
			A 2.	28 33·2	26 23·6	27 28·4	
			A 2 L.	26 56·7	18 16·1	27 36·4	
			A 1 L.	35 05·8	18 47·0	27 24·4*	
				Mean dip at Cheringin...			27 30·8
5.	Palambangan.	...	A 1.	25 01·4	31 19·3	28 10·3	
			A 2.	26 44	29 18·6	28 01·3	
			A 2 L.	27 25·6	28 47·3	28 06·4	
			A 1 L.	35 46·8	19 21·2	28 02*	
				Mean dip at Palambangan			28 05·4
7.	Chebiliang ...		A 1.	25 27·8	32 02·5	28 45·1	
		Madras.	A 2.	27 26·2	29 43·1	28 34·6	
			A 2 L.	27 56·4	29 20·7	28 33·3	
			A 1 L.	36 17·7	19 42·4	28 28*	
				Mean dip at Chebiliang...			28 37·9
9.	Chelangkahan		A 1.	25 01·8	31 38·1	28 20	
			A 2.	27 02·8	29 27·6	28 15·2	
			A 2 L.	27 44·7	29 03·8	28 24	
			A 1 L.	36 04·3	19 53·4	28 26·8*	
				Mean dip at Chelangkahan			28 20·7
12.	Goonong Dādap.		A 1.	24 23·9	30 38·2	27 31	
			A 2.	26 12·5	28 36·9	27 24·7	
			A 1 L.	35 00	19 06·6	27 31*	
				Mean dip at Goonong Dadap			27 28·5
14.	Woorong Goonong.		A 1.	24 12·5	30 39·9	27 26·2	
			A 2.	26 10	28 02	27 06·0	
			A 2 L.	26 43·5	28 04·8	27 24·1	
			A 1 L.	35 10·1	18 47·4	27 26·7*	
			Mean dip at Woorong Goonong				27 20·0
23.	Tanāra.........	...	A 1.	23 43·3	30 22·2	27 02·7	
			A 2.	25 47·3	28 12·7	27 00·0	
			A 2 L.	28 16·0	26 11·1	27 13·5	
			A 1 L.	34 44·0	18 02	26 51*	
				Mean dip at Tanāra			27 02·6

* Correction —28′ for A 1 L.

Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.
				Direct.	Reversed.		
				—	—	—	South.
1846.	JAVA.						—
Nov. 9.	Batavia	...	A 1.	23° 49′·1	30° 24′·1	27° 06′·6	
			A 2.	25 39·4	28 25·5	27 02·5	
			A 2 L.	26 20·3	27 34·3	26 57·3	
		Madras.	A 1 L.	34 51·4	18 04·2	26 55·8*	
				Mean of the four needles			27° 00′·5
12.			A 1.	23 45·1	30 11·1	26 58·1	
			A 2.	25 24·7	28 28·7	26 56·7	
			A 2 L.	26 01·4	27 28·1	26 44·7	
			A 1 L.	34 33·4	18 23·9	26 56·6*	
				Mean of the four needles			26 54·0
				Mean dip at Batavia......			26 57·2
14.		2	A 1.	27 26·4	26 44·5	27 05·4	
		2	A 2.	26 25·9	27 35·4	27 00·3	
		1	A 1.	27 00·0	27 04·2	27 02·1	
		1	A 2.	27 11·0	26 54·1	27 02·6	
		3	A 1.	27 08·7	26 47·8	26 58·2	
		3	A 2.	27 00·7	27 10·9	27 05·8	
General mean found at Batavia by the new needles						27 02·4	
Nov. 21.	Tegu	2	A 1.	29 05·0	28 24·7	28 44·8	
		2	A 2.	29 03	28 18·5	28 40·7	
		2	A 1 L.	28 53·7	28 40·0	28 46·8	
		2	A 2 L.	28 50·0	28 35·2	28 42·6	
		2	A 1.	29 00·6	28 20·2	28 40·4	
		2	A 2.	28 16·2	29 18·2	28 47·2	
		2	A 1 L.	28 51·0	28 33·6	28 42·3	
		2	A 2 L.	28 50·4	28 35·1	28 42·8	
23.		1	A 1.	28 37·7	28 55·1	28 46·4	
		1	A 2.	28 42·1	28 37·4	28 39·8	
		1	A 1 L.	28 56·5	28 30·5	28 43·5	
		1	A 2 L.	28 38·4	28 46·2	28 42·3	
		1	A 1.	28 38·8	28 38·7	28 38·8	
		1	A 2.	28 43·6	28 32·4	28 38	
		1	A 1 L.	28 53·8	28 30 5	28 42·2	
		1	A 2 L.	28 34·8	28 44·4	28 39·6	
		3	A 1.	29 02·0	28 21·1	28 41·5	
		3	A 2.	28 39·5	28 51·2	28 45·3	
		3	A 1 L.	28 50·5	28 36·5	28 43·5	
26.	Pangerango, top of the mountain, Gedê.	3	A 2 L.	28 33·9	28 45·0	28 39·4	28 42·5
		2	A 1.	29 54·9	29 36·7	29 45·8	
		2	A 1 L.	29 48·1	29 37·5	29 42·8	
		2	A 2 L.	29 54·7	29 32·8	29 43·8	
		1	A 1 L.	29 54·1	29 31·0	29 42·5	
		1	A 2 L.	29 33·4	29 44·1	29 38·7	29 42·7
30.	Chunjūr	2	A 1.	28 46·7	28 08·6	28 27·6	
		2	A 2.	28 54·2	28 01·5	28 27·8	
		2	A 1 L	28 35·0	28 20·0	28 27·5	
		2	A 2 L.	28 34·8	28 17·7	28 26·2	
		1	A 1.	28 20·5	28 19·0	28 20·0	
		1	A 2.	28 19·2	28 19·5	28 19·5	
		1	A 1 L.	28 34·5	28 13·2	28 23·9	
		1	A 2 L.	28 17·5	28 24·5	28 20·8	
		3	A 1.	28 31·2	28 05·4	28 18·2	
		3	A 2.	28 21·7	28 26·2	28 24·0	
		3	A 1 L.	28 22·5	28 15·0	28 20·0	
		3	A 2 L.	28 14·1	28 29·9	28 22	28 23·1
Dec. 4.	Kārang Tengga	2	A 1.	28 42·7	28 06·2	28 24·5	
			A 2.	28 53·1	27 53·1	28 23·4	
			A 1 L.	28 25·8	28 07·6	28 16·7	
			A 2 L.	28 28·4	28 11·2	28 19·8	28 21·1
7.	Chebrānok ...	2	A 1.	28 45·2	28 07·8	28 26·5	
			A 2.	28 56·6	28 00·0	28 28·3	
			A 1 L.	28 36·1	28 21·4	28 28·7	28 27·8
8.	Palabuan Rātoo, or Wine Cooper's Bay.	2	A 1.	29 36·5	28 59·5	29 18·0	
			A 2.	29 44·1	28 52·7	29 18·4	
			A 1 L.	29 25·9	29 13·9	29 19·9	
			A 2 L.	29 24·7	29 10·5	29 17·6	29 18·5

* Correction —28′ for A 1 L.

TABLE F.

Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.	Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.
				Direct.	Reversed.							Direct.	Reversed.		
				—	—	—	South.					—	—	—	South.
1846.	JAVA.						—	1847.	JAVA.						—
Dec. 10.	Chilotoe	2	A 1.	29° 08'·7	28° 33'·0	28° 50'·9		Jan. 15.	Cheribon	2	A 1.	28° 47'·1	26° 49'·2	27° 48'·1	
			A 2.	29 17·7	28 21·4	28 49·5					A 2.	28 19·4	27 20·2	27 49·8	
			A 1 L.	28 58·5	28 48·2	28 53·4					A 1 L.	27 54·5	27 47·1	27 50·7	
			A 2 L.	29 10·4	28 32·7	28 51·5	28° 51'·3				A 2 L.	27 59·6	27 37·5	27 48·5	27° 49'·3
11.	Pangangbahan	2	A 1.	29 58·1	29 20·1	29 39·0		18.	Indramāyu ...	2	A 1.	28 32·8	26 27·0	27 29·9	
			A 2.	30 10·2	29 13·8	29 42·0					A 2.	27 58·0	26 56·8	27 27·4	
			A 1 L.	29 46·5	29 35·9	29 41·2					A 1 L.	27 30·6	27 28·2	27 29·4	
			A 2 L.	29 46·8	29 40·4	29 43·6	29 41·4				A 2 L.	27 35·0	27 19 5	27 27·2	27 28·5
13.	Mooāro Chikasso.	2	A 1.	30 14·9	29 48·3	30 06·6		26.	Tegal	2	A 1.	28 55·7	27 01·6	27 58·6	
			A 2.	30 30·1	29 39·5	30 04·8					A 2.	28 32·7	27 33·2	28 03·0	
			A 1 L.	30 11·9	29 57·6	30 04·8					A 1 L.	28 09·3	27 59·3	28 04·3	
			A 2 L.	30 12·7	29 57·4	30 05·0	30 05·3				A 2 L.	28 12·6	27 57·1	28 04·8	28 02·7
14.	Sidang Bārang	2	A 1.	31 07·0	29 15·3	30 11·1		30.	Samārang ...	2	A 1.	28 57·6	27 02·5	28 00·0	
			A 2.	30 38·5	29 42·7	30 10·6					A 2.	28 32·2	27 33·5	28 02·8	
			A 1 L.	30 24·9	30 07·9	30 16·4					A 1 L.	28 07·4	27 57·6	28 02·5	
			A 2 L.	30 19·9	30 03·6	30 11·7					A 2 L.	28 12·4	27 54·0	28 08·5	28 02·2
15.		2	A 1.	31 05·8	29 17·2	30 11·5		Feb. 2.	Japāra	2	A 1.	28 25·8	26 35·4	27 30·6	
			A 2.	30 41·0	29 41·8	30 11·4					A 2.	27 55·8	27 02·5	27 29·1	
			A 1 L.	30 19·2	30 06·6	30 12·9					A 1 L.	27 30·1	27 21·8	27 26·0	
			A 2 L.	30 19·2	30 02·0	30 10·6	30 12·0				A 2 L.	27 32·1	27 16·8	27 24·5	27 27·5
16.	Bejong Petair	2	A 1.	30 25·5	28 35·0	29 30·3		5.	Ambarāwa ...	2	A 1.	30 18·7	28 27·0	29 22·8	
			A 2.	30 00·3	29 04·6	29 32·5					A 2.	29 55·1	29 00·5	29 27·8	29 25·3
			A 1 L.	29 42·0	29 28·3	29 35·2		10.	Balembang ...	2	A 1.	29 56·1	28 01·0	28 58·5	
			A 2 L.	29 41·4	29 23·5	29 32·5	29 33·5				A 2.	29 28·8	28 31·5	29 00·1	
21.	Bandong	2	A 1.	29 24·9	27 30·1	28 27·5					A 1 L.	28 55	29 06·5	29 00·7	
			A 2.	28 56·1	27 59·3	28 27·7					A 2 L.	29 12·0	28 49·1	29 00·5	29 00·0
			A 1 L.	28 35·2	28 24·8	28 30·0		13.	Solo	2	A 1.	30 01·0	28 14·2	29 07·6	
			A 2 L.	28 38·5	28 13·2	28 25·8	28 28·0				A 2.	29 37·4	28 43·8	29 10·6	
		2	A 1.	29 34·4	27 36·5	28 35·5					A 1 L.	29 18·0	29 05·1	29 11·7	
			A 2.	29 02·8	28 09·8	28 36·3					A 2 L.	29 21·8	29 01·3	29 11·5	29 10·3
			A 1 L.	28 38·8	28 29·7	28 34·2		18.	Nyāwee	2	A 1.	29 54·0	27 59·2	28 56·6	
			A 2 L.	28 46·2	28 25·8	28 36·0					A 2.	29 31·2	28 34·6	29 02·9	
		1	A 1.	28 22·5	28 28·9	28 25·7					A 1 L.	28 50·1	28 57·4	28 53·7	28 57·7
			A 2.	28 27·1	28 24·2	28 25·7		22.	Bankāwa, Solo River.	2	A 1.	28 42·4	26 49·4	27 45·9	
			A 1 L.	28 43·6	28 28 1	28 27·0					A 2.	28 11·0	27 20·7	27 45·8	
			A 2 L.	28 31·5	28 29·2	28 29·2					A 1 L.	28 53·1	27 45·1	27 49·1	
21.		3	A 1.	28 53·0	28 18·0	28 35·5					A 2 L.	27 55·0	27 30·2	27 42·6	
			A 1 L.	28 39·8	28 34·1	28 36·9					A 1 L.	27 46·7	27 38	27 42·3	27 45·1
			A 1 L.	28 26·0	28 38·4	28 32·2	28 31·4	25.	Soorabāya ...	2	A 1.	29 38·2	27 48·5	28 43·3	
24.	Garoet	2	A 1.	29 54·1	28 03·5	28 58·8					A 2.	29 18·8	28 20·0	28 49·4	
			A 2.	29 24·5	28 34·0	28 59·2					A 1 L.	28 51·1	28 40·4	28 45·7	
			A 1 L.	29 07·4	28 51·6	28 59·5					A 2 L.	28 53·5	28 53·8	28 53·6	
			A 2 L.	29 06·5	28 51·4	28 59·0		26.			A 1.	29 38·2	27 48·5	28 43·3	
		1	A 1.	28 55·7	28 57·9	28 56·8					A 2.	29 21·9	28 29·2	28 55·5	
			A 2.	28 54·3	29 01·5	28 57·9	28 58·5			2	A 1 L.	29 01·7	28 54·0	28 57·8	
28.	Permangpek.	2	A 1.	31 05·6	29 15·3	30 10·5					A 2 L.	28 57·6	28 48·2	28 52·9	28 50·8
			A 2.	30 37·4	29 43·8	30 10·6		Mar. 23.	Sūmcnap	...	A 1.	28 36	26 47 1	27 41·5	
			A 1 L.	30 16·0	30 05·2	30 10·6					A 2.	28 05	27 17·5	27 41·2	
			A 2 L.	30 20·3	30 02·6	30 11·4					A 1 L.	27 48·1	27 40·8	27 44·5	
29.		2	A 1.	31 07·4	29 18·6	30 13·0					A 2 L.	27 49·3	27 39·4	27 44·4	
			A 2.	30 39·4	29 46·7	30 13·1		26.		...	A 1.	28 40·7	26 29·5	27 45·1	
			A 1 L.	30 18·7	30 05·6	30 12·1					A 2.	28 14	27 19	27 46·5	
			A 2 L.	30 22·7	30 05·4	30 14·1	30 11·8				A 1 L.	27 48·9	27 38·9	27 43·9	
1847.											A 2 L.	27 48·4	27 39	27 43·9	
Jan. 1.	Cherūgnūktok.	2	A 1.	31 03·7	29 13·7	30 08·4		31.		...	A 1.	28 37·2	26 27·3	27 42·2	
			A 2.	30 39·2	29 41·4	30 10·3					A 2.	28 10·8	27 15	27 42·8	
			A 1 L.	30 09·1	30 06·7	30 07·9					A 1 L.	27 49·1	27 42·9	27 46·0	
			A 2 L.	30 15·0	29 57·2	30 06·1	30 08 2				A 2 L.	27 46	27 35	27 40·5	27 43·8
6.	Kālipoochen .	2	A 1.	30 46·6	28 54·7	29 50·6		April 7.	Pulo Kuneeang.		A 1.	28 15·4	26 28·1	27 23·7	
			A 2.	30 21·4	29 20·8	29 51·1					A 2.	27 40·7	26 55	27 17·8	
			A 1 L.	29 56·6	29 48·2	29 52·3					A 1 L.	27 30	27 19·6	27 24·8	
			A 2 L.	29 59·4	29 42·4	29 49·9	29 51·2	8.			A 2 L.	27 27·3	27 14·5	27 20·9	
8.	Banjeer	2	A 1.	30 02·5	28 10·2	29 06·7		8.			A 1.	28 14·5	26 24·1	27 19·3	
			A 2.	29 35·2	28 40·3	29 07·7	29 07·2				A 2.	27 45·5	26 53·7	27 19·6	
10.	Chāwee	2	A 1.	29 36·1	27 39·4	28 37·7					A 1 L.	27 30·6	27 21·5	27 26	
			A 2.	29 06·6	28 14·2	28 40·4					A 2 L.	27 36·8	27 19	27 27·9	
			A 1 L.	28 42·7	28 38·1	28 40·2		8.			A 1.	28 22·5	26 29·9	27 26·2	
			A 2 L.	28 46·6	28 30·2	28 38·4	28 39·2				A 2.	27 54·6	26 57·9	27 26·2	
12.	Samadang ...	2	A 1.	28 53·5	26 55·8	27 54·6		9.			A 1 L.	27 23·6	27 17·8	27 20·7	
			A 2.	28 26·5	27 28·0	27 57·2					A 2 L.	27 29·3	27 11·2	27 19·2	27 23·6
			A 1 L.	28 04·0	27 55·2	27 59·6		26.	Bezooki	...	A 1.	29 57·5	28 10·4	29 03·9	
			A 2 L.	28 07·2	27 50·2	27 58·7	27 57·5				A 2.	29 33·2	28 38·1	29 05·6	

TABLE F.

Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.
				Direct.	Reversed.		
				—	—	—	South.
1847.	JAVA.						—
April 26.	Bezooki	...	A 1 L.	29° 08′·7	29° 01′·8	29° 05′·2	
			A 2 L.	29 15·2	29 01·0	29 08·1	29° 05′·7
May 11.	Kedeeri	...	A 1.	30 42·8	28 49	29 45·9	
			A 2.	30 14·0	29 13·5	29 43·7	
			A 1 L.	29 55·5	29 47·2	29 51·2	
			A 2 L.	29 59·5	29 44·7	29 52·1	
12.			A 1.	30 42·6	28 53·6	29 48·1	
			A 2.	30 17·1	29 24·0	29 50·5	
			A 1 L.	29 55·9	29 46·8	29 51·3	
			A 2 L.	30 03·2	29 45·5	29 54·3	
13.			A 1.	30 42·8	28 51·4	29 47·1	
			A 2.	30 19·6	29 22·6	29 51·1	
			A 1 L.	29 54·3	29 49·3	29 51·8	
			A 2 L.	30 02·5	29 43·9	29 53·2	29 50·0
May 21.	Patchitan......	2	A 1.	31 26·9	29 38·5	30 32·7	
			A 2.	31 03·1	30 06·5	30 34·8	
			A 1 L.	30 40·8	30 26·5	30 33·6	
			A 2 L.	30 45·1	30 29·1	30 37·1	30 34·5
June 1.	Munoori	2	A 1.	30 12·6	28 22·0	29 17·3	
			A 2.	29 46·2	28 52·4	29 19·2	
			A 1 L.	29 21·6	29 18·1	29 19·8	
			A 2 L.	29 27·5	29 11·8	29 19·6	29 19·0
6.	Kārang Bolong.	2	A 1.	30 45·7	28 58·5	29 52·1	
			A 2.	30 25	29 23·9	29 54·4	
			A 1 L.	29 58·3	29 53·5	29 55·9	
			A 2 L.	30 03·5	29 46·5	29 55·0	29 54·4
9.	Chilāchap ...	2	A 1.	30 39·3	28 46	29 42·6	
			A 2.	30 11·2	29 13·4	29 42·3	
			A 1 L.	29 48	29 47·5	29 47·5	
			A 2 L.	29 37·7	29 37·7	29 44·7	29 44·3
12.	Aji Bārang ...	2	A 1.	28 15·6	26 22·6	27 19·1	
			A 2.	27 42·3	26 54·5	27 18·4	
			A 1 L.	27 27·5	27 28·4	27 27·9	
			A 2 L.	27 27·8	27 13·8	27 21·5	27 20·8
July 6.	Batavia	2	A 1.	28 02	26 10·3	27 06·1	
			A 2.	27 31·5	26 34·5	27 03·0	
			A 1 L.	27 11·5	27 08·6	27 09 8	
			A 2 L.	27 15·6	26 57·1	27 06·3	
		2	A 1.	28 02·2	26 10·4	27 06·3	
			A 2.	27 31	26 35·0	27 03·4	
			A 1 L.	27 11·0	27 10 3	27 10·6	
			A 2 L.	27 21·8	27 00·8	27 11·3	
7.		2	A 1.	28 06·4	26 12·7	27 09·5	
			A 2.	27 31·3	26 38·5	27 04·9	
			A 1 L.	27 08·5	27 08·2	27 08·3	
			A 2 L.	27 17·5	26 56·1	27 06·6	
		2	A 1.	28 03·8	26 13·3	27 08·5	
			A 2.	27 29 9	26 41·7	27 05·8	
			A 1 L.	27 12·4	27 09·6	27 11·0	
			A 2 L.	27 20·9	26 58·9	27 09·9	
9.		2	A 1.	28 05·3	26 09·5	27 07·4	
			A 2.	27 15	26 39·5	27 03·5	
			A 1 L.	27 11·0	27 09·3	27 10·1	
			A 2 L.	27 19·6	26 59·8	27 09·7	
		2	A 1.	28 05·5	26 11·7	27 08·6	
			A 2.	27 28·3	26 38·5	27 03·4	
			A 1 L.	27 09·9	27 11·1	27 10·5	
			A 2 L.	27 16·1	26 58·5	27 07·3	
10.		1	A 1.	27 07·2	27 09·8	27 08·5	
			A 1 L.	27 03·4	27 23·0	27 13·2	
			A 2 L.	27 06·9	27 07·9	27 07·4	
		1	A 1.	27 11·5	27 06·0	27 08·7	
			A 1 L.	27 02 6	27 21·8	27 12·7	
			A 2 L.	27 06·0	27 09·6	27 07·8	
13.		1	A 1.	27 07·9	27 05·4	27 06·6	
			A 1 L.	27 00·5	27 20·0	27 10·2	
			A 2 L.	27 06·2	27 06·1	27 06·1	
14.		1	A 1.	27 06·5	27 04·5	27 05·5	
			A 1 L.	26 58·9	27 16·7	27 07·8	
			A 2 L.	27 03·2	27 06·4	27 04·8	
13.		3	A 2.	26 58·2	27 22·3	27 10·2	
			A 1 L.	27 23·5	27 00·7	27 12·5	
				—	—	—	South.
1847.	JAVA.						—
July 14.	Batavia	3	A 2.	26° 53′·7	27° 24′	27° 08′·8	
			A 1 L.	27 21·1	26 58·3	27 09·7	
14.		3	A 2.	26 57·6	27 17·6	27 07·6	
			A 1 L.	27 20·3	27 03·9	27 12·1	
		3	A 2.	26 57·5	27 17·4	27 07·4	
			A 1 L.	27 22·4	27 00·2	27 11·3	27° 08′·2
17.		F.	B.	27 11·8	......	27 11·8	
			B.	27 09·0	......	27 09·0	
			B.	27 13·7	......	27 13·7	
				27 17·6	......	27 17·6	
19.			B.	27 12	......	27 12	
				27 12·5	......	27 12·5	
				25 59·6	28 05	27 02·3	
	SUMĀTRA.			26 01·7	28 07·3	27 04·5	27 09·3
Aug. 18.	Telok Betong, Lampong Bay.	2	A 1.	27 06·7	25 13·8	26 10·2	
			A 2.	26 42·6	25 44·4	26 13·5	
			A 1 L.	26 16·3	26 14·2	26 15·2	
			A 2 L.	26 24·9	26 06·3	26 15·6	26 14·8
Sept. 3.	Poolo Bay near Bencoolen.	2	A 1.	24 52·9	22 44	23 48·4	
			A 2.	24 22·7	23 22·1	23 52·4	
			A 1 L.	24 03·2	23 56·3	23 58·4	
			A 2 L.	24 02·2	23 42·6	23 52·4	
		1	A 1.	23 51·8	23 50·3	23 51·0	
			A 1 L.	23 59·4	23 56·2	23 57·8	
			A 2 L.	23 48·2	23 50·5	23 49·3	
		2	A 1.	24 49	22 49·3	23 49·1	
			A 2.	24 25·2	23 20·3	23 52·7	
			A 1 L.	24 03	23 52·0	23 57·5	
			A 2 L.	24 04·6	23 45	23 54·8	
4.		2	A 1.	24 54·8	22 51·2	23 53	
			A 2.	24 24·4	23 22·8	23 53·6	
			A 1 L.	23 55·6	23 53·9	23 53·7	
			A 2 L.	24 02·9	23 43·7	23 53·3	
		3	A 2.	23 43	24 04·4	23 53·7	
			A 1 L.	24 00·7	23 42·1	23 51·4	23 53·1
Oct. 18.	Padang.........	2	A 1.	19 33·8	17 20·7	18 27·2	
21.			A 2.	19 11·3	18 03·5	18 37·4	
			A 1 L.	18 37·5	18 36·8	18 37·4	
			A 2 L.	18 32	18 22·8	18 27·4	
23.		1	A 1.	18 26·2	18 25·7	18 26·0	
			A 1 L.	18 20·2	18 33·3	18 26·7	
			A 2 L.	18 22·8	18 31·1	18 26·9	
25.		3	A 2.	18 26	18 50·6	18 38·3	
			A 1 L.	18 46·7	18 29·3	18 38 0	18 31·7
				Poles Direct.			Cor. Dip.
		1	A 1, A 1 L.	18 36·4	18 40·6	18 38·5	
			A1 L., A2 L.	18 43·3	18 39·2	18 41·2	
			A 1, A 1 L.	18 31·9	18 41·4	18 36·6	
			A1 L., A2 L.	18 37·9	18 36·2	18 37·0	
			A 1, A 1 L.	18 38·2	18 48·1	18 43·1	
			A1 L., A2 L.	18 45·8	18 48·1	18 47	
Mean of the three needles with poles unchanged =						18 40·6	
And the true dip has been found to be .... =						18 31·7	
Correction to be applied for the survey in Sumatra						+08·9	
Nov. 1.	Solok	1	A 1, A 1 L.	17 53·2	18 00·1	17 56·6	
			A1 L., A2 L.	17 54·3	18 01·5	17 57·9	
		1	A 1, A 1 L.	17 53	18 02·2	17 57·6	
			A1 L., A2 L.	18 01·7	17 57·8	17 59·7	
2.		1	A 1, A 1 L.	17 53·0	18 05·6	17 59·3	
			A1 L, A2 L.	18 03·7	18 05·1	18 04·4	17 50·3
5.	Sijonjong......	1	A 1, A 1 L.	17 51·8	18 00·6	17 56·2	
			A1 L., A2 L.	18 03·8	17 56·7	18 00·2	17 49·3
8.	Bua Pārjāng .	1	A 1, A 1 L.	17 16·2	17 16·3	17 16·2	
			A1 L., A2 L.	17 19·9	17 23·2	17 21·5	17 10·9
10.	Pāyacombo ...	1	A 1, A 1 L.	16 41·9	16 47·5	16 44·7	
			A1 L., A2 L.	16 48·1	16 48·9	16 48·5	16 37·7

TABLE F.

Date.	Name of Station.	Circle.	Needle.	Poles direct.		Dip.	Corr. Dip.
				—	—	—	South.
1847.	SUMĀTRA.						—
Nov. 11.	Fort Vande Capellen.	1	A 1, A 1 L.	17° 15′·2	17° 21′·5	17° 18′·3	
			A1 L., A2 L.	17 19·7	17 26·7	17 23·2	17° 11′·8
14.	Padang Panjang.	1	A 1, A 1 L.	17 52·9	17 55·9	17 54·4	
			A1 L., A2 L.	17 54·8	18 00·3	17 57·5	17 47·0
16.	Fort de Kock.	1	A 1, A 1 L.	17 06·8	17 07·4	17 07·5	
			A1 L., A2 L.	17 08·6	17 10·5	17 09·5	16 59·4
17.	Menindjo ...	1	A1 L., A2 L.	17 03·8	17 10·1	17 07·4	
			A1 L., A2 L.	17 11·0	17 11·6	17 11·3	17 00·4
18.	Balembangan.	1	A 1, A 1 L.	16 48·0	16 58·2	16 53·5	
			A1 L., A2 L.	16 58·8	16 58·1	16 58·5	16 47·1
19.	Peesang	1	A 1, A 1 L.	16 38·0	16 43·1	16 40·5	
			A1 L., A2 L.	16 46·2	16 43·0	16 44·6	
		1	A 1, A 1 L.	16 36·8	16 43·1	16 39·9	
			A1 L., A2 L.	16 43	16 44·5	16 43·7	16 33·2
20.	Bonjol	1	A 1, A 1 L.	16 42·5	16 48·6	16 45·5	
			A1 L., A2 L.	16 48·6	16 49·2	16 48·9	16 38·3
21.	Loobisikapping.	1	A 1, A 1 L.	16 11·3	16 17·6	16 14·5	
			A1 L., A2 L.	16 17·8	16 21·2	16 19·5	16 08·1
22.	Batoo Bedindi	1	A 1, A 1 L.	15 50·7	16 00·2	15 55·4	
			A1 L., A2 L.	16 00·6	16 00·5	15 57·9	15 49
23.	Lender.........	1	A 1, A 1 L.	15 47·3	15 35·4	15 41·3	
			A1 L., A2 L.	15 43·7	15 49·6	15 46·6	15 35·0
24.	Rau	1	A 1, A 1 L.	15 37·9	15 49·8	15 43·8	
			A1 L., A2 L.	15 48·7	15 49·2	15 49·0	
25.		1	A 1, A 1 L.	15 35·5	15 48·4	15 41·9	
			A1 L., A2 L.	15 49·0	15 50·9	15 50·0	15 37·2
26.	Pionghay......	1	A 1, A 1 L.	15 48·0	16 03·8	15 55·9	
			A1 L., A2 L.	16 02·0	16 02	16 02	15 50·0
27.	Batong.........	1	A 1, A 1 L.	15 40·9	15 54·5	15 47·7	
			A1 L., A2 L.	15 53·7	15 51·9	15 52·8	15 41·3
28.	Kotanopan ...	1	A 1, A 1 L.	15 18·3	15 33·1	15 25·7	
			A1 L., A2 L.	15 33·1	15 30·0	15 31·5	15 19·7
29.	Tāna Bātoo ...	1	A 1, A 1 L.	15 01·6	15 18·5	15 10·0	
			A1 L., A2 L.	15 14·7	15 12·7	15 13·7	15 02·9
Dec. 1.	Fort Elout ...	1	A 1, A 1 L.	14 44·5	15 01·7	14 53·1	
			A1 L., A2 L.	15 01·9	14 55·7	14 58·8	14 47·9
3.	Singalāngan...	1	A 1, A 1 L.	14 11·5	14 24·2	14 17·8	
			A1 L., A2 L.	14 24·6	14 20·3	14 22·5	14 11·7
6.	Padang Sidompang.	1	A 1, A 2 L.	13 46·8	14 00·5	13 53·6	
			A1 L., A2 L.	14 00·4	13 55·3	13 57·9	13 46 8
11.	Sibogha	1	A 1, A 1 L.	13 03·2	13 14·2	13 08·6	
			A1 L., A2 L.	13 15·8	13 11·8	13 13·8	
13.		1	A 1, A 1 L.	13 04·8	13 19·0	13 11·9	
			A1 L., A2 L.	13 18·3	13 14·9	13 16·6	
15.		1	A 1, A 1 L.	13 06·0	13 18·2	13 12·1	
			A1 L., A2 L.	13 18·7	13 16·3	13 17·5	
16.		1	A 1, A 1 L.	13 04·3	13 19·8	13 12·0	
			A1 L., A2 L.	13 18·1	13 14·4	13 16·2	13 04·7
19.	Bāros	1	A 1, A 1 L.	12 58	13 10·9	13 04·4	
			A1 L., A2 L.	13 06·8	13 06·5	13 06·6	
		1	A 1, A 1 L.	12 57	13 10·9	13 03·9	
			A1 L., A2 L.	13 11·8	13 03·8	13 07·8	
20.		1	A 1, A 1 L.	13 00·4	13 14·1	13 07·2	
			A1 L., A2 L.	13 13·4	13 07·8	13 10·6	12 57·8
23.	Sinkel	1	A 1, A 1 L.	12 24·3	12 35·5	12 29·9	
			A1 L., A2 L.	12 33·5	12 30·0	12 31·7	
25.		1	A 1, A 1 L.	12 26·1	12 36·0	12 31·0	
			A1 L., A2 L.	12 38·3	12 34·6	12 36·4	12 23·3
31.	Pulonias, Goonong Satoolie	1	A 1, A 1 L.	14 04·2	14 20·3	14 12·2	
			A1 L., A2 L.	14 19·2	14 14·4	14 16·9	14 05·6
1848.							
Jan. 10.	Nātal	1	A 1, A 1 L.	15 30	15 39·1	15 34·5	
			A1 L., A2 L.	15 40·3	15 47·1	15 43·7	
11.		1	A 1, A 1 L.	15 34·5	15 48·4	15 41·5	
			A 1, A 1 L.	15 49·3	15 48·6	15 49	
12.		1	A1 L., A2 L.	15 31·0	15 44·2	15 37·6	
			A1 L., A2 L.	15 42·5	15 40·1	15 41·2	
13.		1	A 1, A 1 L.	15 29 3	15 46·4	15 37·8	15 32·2
			A1 L., A2 L.	15 45·4	15 42·7	15 44·0	

Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.
				Direct.	Reversed.		
				—	—	—	South.
1848.							—
Feb. 14.	Singapore ...	2	A 1.	14° 01′·9	11° 46′·5	12° 54′·2	
15.			A 2.	13 28·8	12 19·3	12 54·1	
			A 1 L.	12 59·0	12 51·9	12 55·4	
			A 2 L.	13 03·2	12 47·4	12 55·3	12° 54′·7
			A 1.	14 04·2	11 49·5	12 56·8	
			A 2.	13 34·7	12 19·1	12 56·9	
			A 1 L.	13 01·1	12 51·0	12 56·0	
			A 2 L.	13 05·8	12 45·6	12 55·7	12 56·3
16.			A 1.	14 04·6	11 57·3	13 00·9	
19.			A 2.	13 36·0	12 20·8	12 58·0	
			A 1 L.	13 01·6	12 33·3	12 57·4	
			A 2 L.	13 06·2	12 56·5	12 58·3	12 58·3
			A 1.	14 09·3	11 51·1	13 00·2	
			A 2.	13 29·8	12 22·3	12 56·0	
			A 1 L.	13 00·1	12 55·0	12 57·5	
			A 2 L.	13 07·5	12 57·0	12 59·7	12 58·2
21.		2	A 1.	14 10·4	11 54·6	13 02·5	
22.			A 2.	13 29·6	12 19·1	12 54·3	
			A 1 L.	13 05·0	13 00·1	13 02·5	
			A 2 L.	13 10·5	12 48·5	12 59·5	12 59·7
		2	A 1.	14 04·9	11 54·5	12 59·7	
			A 2.	13 31·3	12 26·3	12 58·8	
			A 1 L.	13 03·9	12 59·4	13 01·6	
			A 2 L.	13 07·1	12 52·5	12 59·8	13 00·0
22.		2	A 1.	14 09·2	11 43·7	12 56·4	
28.			A 2.	13 28·3	12 24·1	12 56·2	
			A 1 L.	13 09·4	12 57·4	13 03·4	
			A 2 L.	13 06·6	12 42·4	12 54·5	12 57·6
		2	A 1.	14 06·8	11 45·5	12 56·1	
			A 2.	13 31·8	12 21·5	12 56·6	
			A 1 L.	13 06·8	12 59·9	13 03·3	
			A 2 L.	13 06·7	12 42·5	12 54·6	12 57·6
24.		2	A 1.	14 04	11 48·6	12 56·3	
Mar. 1.			A 2.	13 29·7	12 16·3	12 53·0	
			A 1 L.	12 55·9	12 53·2	12 54·5	
			A 2 L.	13 02·6	12 43·1	12 52·7	12 54·1
		2	A 1.	14 07·3	11 45·0	12 56·1	
			A 2.	13 28·6	12 18·3	12 53·4	
			A 1 L.	13 03·2	13 00·7	13 02·0	
			A 2 L.	13 02·6	12 44·5	12 53·3	12 56·2
Feb. 26.		2	A 1.	14 04·3	11 44·5	12 54·4	
Mar. 3.			A 2.	13 29·3	12 20	12 54·6	
			A 1 L.	12 58·1	12 53·7	12 55·9	
			A 2 L.	13 06·1	12 41·7	12 53·9	12 54·7
		2	A 1.	14 04·7	11 46·9	12 55·8	
			A 2.	13 33·9	12 16·5	12 58·2	
			A 1 L.	13 00·3	12 55·5	12 57·9	
			A 2 L.	13 04·2	12 41·8	12 53·0	12 56·2
Feb. 23.		2	A 1.	14 04·0	11 46·7	12 55·3	
Mar. 1.			A 2.	13 28·3	12 14·7	12 51·6	
			A 1 L.	13 01·5	12 57·5	12 59·4	
			A 2 L.	13 05·7	12 45·8	12 55·7	12 55·5
			A 1.	14 04·8	11 46·6	12 55·7	
			A 2.	13 29·0	12 15·2	12 52·1	
			A 1 L.	13 02·0	12 58·7	13 00·3	
			A 2 L.	13 07·1	12 44·0	12 55·5	12 55·5
				Mean dip at Singapore...			12 56·8
28.	Mount Ophir, near Malacca.	2	A 1.	10 58·0	8 49·0	9 53·5	
			A 2.	10 27·7	9 18·3	9 53·0	
			A 1 L.	9 58·5	9 59·5	9 59·0	
			A 2 L.	10 10·3	9 45·6	9 57·9	9 55·8
May 3.	Pulo Labooan.	2	A 1.	3 55·0	1 45·3	2 50·1	
			A 2.	3 27·7	2 20·1	2 53·9	
			A 1 L.	3 01·6	2 53·0	2 57·3	
			A 2 L.	3 05·5	2 41·2	2 53·3	
4.		1	A 1.	2 54·3	2 54·2	2 54·2	
			A 1 L.	2 41·4	3 10	2 55·7	
			A 2 L.	2 43·2	2 54·9	2 49·0	
		3	A 2.	2 37·3	3 07·0	2 52·1	
			A 1 L.	3 07·2	2 38·6	2 52·9	2 53·1
5.							

TABLE F.

Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.
				Direct.	Reversed.		
				+	+	+	North.
1848.	MINDANĀO.						+
May 25.	Sambooanga.	1	A 1 L.	1° 35′·8	1° 07′·3	1° 21′·5	
			A 2 L.	1 27·1	1 10·2	1 18·6	
			A 1.	1 19·7	1 17·6	1 18·6	
26.		3	A 2.	1 35·7	1 09·1	1 22·4	
			A 1 L.	2 08·2	1 37·4	1 22·8	
		2	A 1.	0 08·3	2 26·5	1 17·4	
			A 2.	0 39·8	1 57·0	1 18·4	
			A 1 L.	1 13·1	1 19·0	1 16·0	
			A 2 L.	1 06·9	1 28·3	1 17·6	1° 19′·3
	CELEBES.			—	—	—	South.
June 21.	Keemah	2	A 1.	12 07·0	10 00·8	11 03·9	—
			A 2.	11 40·3	10 28·8	11 04·5	
			A 1 L.	11 07·3	10 58·3	11 02 8	
			A 2 L.	11 14·0	10 52·4	11 03·2	
		1	A 1.	10 58·1	10 59·7	10 58·9	
		3	A 2.	10 48·6	11 14·0	11 01·3	
			A 1 L.	11 16·3	10 58·3	11 07·3	
		1	A 1 L.	10 46·0	11 14·2	11 00·1	
			A 2 L.	10 56·9	11 07·3	11 02·1	11 02·7
27.	Tondāno	1	A 1.	C.* 3·0	10 53·6	10 56·6	
			A 1 L.	C. 16·7	10 38·7	10 55·4	
			A 2 L.	C. 5·8	10 49·1	10 54·9	10 55·6
29.	Manādo	1	A 1.	C. 3·0	10 42·4	10 45·4	
			A 1 L.	C. 16·7	10 29·1	10 45·8	
	COCOS.		A 2 L.	C. 5·8	10 37·6	10 43·4	10 44·9
Aug. 26.	Direction Island.	1	A 1.	C. 3·0	39 20·5	39 23·5	
			A 2.	39 16·4	C. 6·0	39 22·4	
			A 2 L.	39 18·1	C. 3·0	39 21·1	
		2	A 1.	40 14·8	38 27·6	39 21·2	
			A 2.	39 42·8	38 56·5	39 19·6	
			A 1 L.	39 20·2	39 16·8	39 18·5	
			A 2 L.	39 30·1	39 07·8	39 18·9	
Sept. 6.		3	A 2.	39 14·3	39 28·5	39 21·4	
			A 1 L.	39 28·8	39 12·8	39 20·8	
7.		3	A 2.	39 13·8	39 27·2	39 20·5	
			A 1 L.	39 27·8	39 08·8	39 18·3	
		2	A 1.	40 08·6	38 29·3	39 18·9	
			A 2.	39 40·6	38 56·1	39 18·3	
			A 1 L.	39 23·7	39 21·3	39 22·5	
			A 2 L.	39 29·7	39 09·7	39 19·7	
8.		1	A 1.	C. 3·0	39 17·1	39 20·1	
			A 1 L.	39 9·4	C. 6·0	39 15·4	
			A 2 L.	39 16·3	C. 3·0	39 19·3	
		2	A 1.	40 14·3	38 30·1	39 22·2	
			A 2.	39 35·3	39 05·3	39 20·3	
			A 1 L.	39 26·8	39 19·5	39 23·1	
			A 2 L.	39 30	39 05·6	39 17·8	
		3	A 2.	39 18	39 23·5	39 20·7	
			A 1 L.	39 26·6	39 12·0	39 19·3	
11.		1	A 1.	C. 3·0	39 18·0	39 21·0	
			A 1 L.	39 13·5	C. 6·0	39 19·5	
			A 2 L.	39 18·1	C. 3·0	39 21·1	
25.		1	A 1.	C. 3·0	39 18·0	39 21·0	
			A 1 L.	39 14·5	C. 6·0	39 20·5	
			A 2 L.	39 14·8	C. 3·0	39 17·8	
		2	A 1.	40 09·7	38 29·5	39 19·6	
			A 2.	39 34·6	38 55·1	39 14·8	
			A 1 L.	39 17·5	39 20	39 18·7	
			A 2 L.	39 31·4	39 05·3	39 18·4	
		3	A 2.	39 14·7	39 26·6	39 20·6	
			A 1 L.	39 30·0	39 15·3	39 22·6	39 20
Nov. 10.	Singapore ...	1	A 1.	C. 0	12 56·4	12 56·4	
			A 1 L.	12 35·0	C. 16·3	12 51·3	
			A 2 L.	12 55·0	C. 2·0	12 57·0	
13.		2	A 1.	13 59·5	11 48·2	12 53·8	
			A 2.	13 28·3	12 15·2	12 51·7	
			A 1 L.	12 46·6	12 57·7	12 52·1	
			A 2 L.	13 08·0	12 42·5	12 55·2	
		3	A 2.	12 39·4	13 14·0	12 56·7	
			A 1 L.	13 16·7	12 46·4	13 01·5	
14.		3	A 1 L.	13 15·3	12 49·2	13 02·2	
			A 2.	12 54·8	13 15·4	13 05·1	
				—	—	—	South.
1848.							
Nov. 14.	Singapore ...	2	A 2 L.	13° 16′	12° 53′·6	13° 04′·8	
			A 1 L.	13 01·3	13 02·1	13 01·7	
			A 2.	13 28·8	12 20·5	12 54·6	
			A 1.	14 03·5	11 53·7	12 58·6	
		1	A 2 L.	12 57·6	C. 2	12 59·6	
			A 1 L.	12 44·1	C. 16·3	13 00·4	
			A 1.	C. 0	12 59·5	12 59·5	
		1	A 1.	C. 0	12 54·3	12 54·3	
			A 1 L.	12 41·2	C. 16·3	12 57·5	
			A 2 L.	12 54·3	C. 2·0	12 56·3	
		1	A 2 L.	12 56·7	C. 2·0	12 58·7	
			A 1 L.	12 45·6	C. 16·3	13 01·9	
			A 1.	C. 0	12 52·3	12 52·3	
24.		1	A 1.	C. 0	12 51·3	12 51·3	
			A 1 L.	12 41·1	16·3	12 57·4	
			A 2 L.	13 00·3	2·0	13 02·3	
		2	A 1.	14 03·4	11 48·4	12 55·9	
			A 2.	13 27·1	12 13·6	12 50·3	
			A 1 L.	13 02·3	13 07	13 04·6	
			A 2 L.	13 13·5	12 50·8	13 02·1	
		3	A 2.	13 06·2	12 51·8	12 59·0	
			A 1 L.	13 12·8	12 49·1	13 00·9	
		1	A 1.	C. 0	12 57·8	12 57·8	
			A 1 L.	12 45·6	C. 16·3	13 01·9	
			A 2 L.	12 57·0	C. 2	12 59·0	
		2	A 1.	14 01·9	11 51·5	12 56·6	
			A 2.	13 29·0	12 17·8	12 53·4	
			A 1 L.	12 58·2	13 05·8	13 02·0	
			A 2 L.	13 11·4	12 46·0	12 58·7	
		3	A 2.	12 53·6	13 16·2	13 04·9	
			A 1 L.	13 19·2	12 51·9	13 05·5	
Dec. 1.		3	A 2.	12 45·2	13 11·5	12 58·2	
14.			A 1 L.	12 45·6	13 18·3	13 01·9	
		3	A 2.	12 48·7	13 17·3	13 03·0	
			A 1 L.	12 52·8	13 21·5	13 07·1	
5.		3	A 2.	12 48·9	13 13·9	13 01·4	
15.			A 1 L.	13 20	12 47·8	13 03·9	
		3	A 2.	12 50·0	13 18·0	13 04·0	
			A 1 L.	13 19·2	12 47·4	13 03·3	
6.		3	A 2.	12 49·6	13 13·6	13 01·6	
15.			A 1 L.	13 15·5	12 43·2	12 59·3	
		3	A 2.	12 49·7	13 23·2	13 06·4	
			A 1 L.	13 25·3	12 46·7	13 06 0	
7.		3	A 2.	12 44·2	13 13	12 58·6	
16.			A 1 L.	13 13·8	12 49·9	13 01·8	
		3	A 2.	12 50·1	13 13·3	13 01·6	
			A 1 L.	13 16·7	12 48·8	13 02·7	
8.		3	A 2.	12 47·8	13 10·6	12 59·2	
16.			A 4 L.	13 11·7	12 46·8	12 59·2	
		3	A 1 L.	13 16·8	12 51·5	13 04·1	
			A 2.	12 47·3	13 14	13 00·7	
12.		1	A 1.	C. 0	12 55·3	12 55·3	
19.			A 1 L.	12 44·3	C. 16·3	13 00·6	
			A 2 L.	12 54·5	C. 2	12 56·5	
		1	A 2 L.	12 55·9	C. 2	12 57·9	
			A 1 L.	12 46·1	C. 16·3	13 02·4	
			A 1.	C. 0	12 58·6	12 58·6	
12.		2	A 1.	13 59	11 44·7	12 51·8	
28.			A 2.	13 26·9	12 14·5	12 50·7	
			A 1 L.	12 58·8	13 06·6	13 02·7	
			A 2 L.	13 09·7	12 47·7	12 58·7	
		2	A 2 L.	13 15·8	12 48·6	13 02·2	
			A 1 L.	13 03·7	13 08·3	13 06·0	
			A 2	13 30·1	12 14·1	12 52·1	
			A 1	14 06·5	11 47·2	12 56·8	
12.		3	A 2.	12 47·4	13 11·5	12 59·4	
Dec. 28.			A 1 L.	13 20	12 51·4	13 05·7	
		3	A 1 L.	13 21·2	12 48·5	13 04·8	
			A 2.	12 47·5	13 14·1	13 00·8	12° 59′·4

* C. the correction applied to the needle, the poles remaining unchanged.

TABLE F.

Date.	Name of Station.	Circle.	Needle.	Poles.		Dip.	Mean Dip.
				Direct.	Reversed.		
				—	—	—	South.
1849.							—
Jan. 2.	Malacca	1	A 1.	C.° ′0	11° 27′·4	11° 27′·4	
			A 1 L.	11 10·8	C. 16·3	11 27·1	
			A 2.	11 27·1	C. 2·0	11 29·1	
3.		2	A 1.	12 36·3	10 18·2	11 27·2	
			A 2.	12 04·9	10 48·7	11 26·8	
			A 1 L.	11 38·1	11 23·6	11 30·8	
			A 2 L.	11 42·0	11 13·2	11 27·6	
		3	A 2.	11 04·6	11 49·8	11 27·2	
			A 1 L.	11 43·2	11 12·0	11 27·6	11° 27′·9
10.	Pulo Dinding.	1	A 1.	7 31·3	7 31·6	7 31·4	
			A 1 L.	7 14·7	7 47·4	7 31·0	
			A 2 L.	7 26·9	7 30·9	7 28·9	
		2	A 1.	8 42·6	6 24·4	7 33·5	
			A 2.	8 07·4	6 58·7	7 33·0	
			A 1 L.	7 34·7	7 38·4	7 36·5	
			A 2 L.	7 50·3	7 27·7	7 39·0	
		3	A 2.	7 18·7	7 56·2	7 37·4	
			A 1 L.	7 46·1	7 22·4	7 34·2	7 33·9
20.	Pulo Penang .	1	A 1.	5 00·4	4 57·5	4 59·0	
			A 1 L.	4 34·3	5 11·0	4 52·6	
			A 2 L.	4 48·9	5 01·2	4 55·0	
		2	A 1.	6 07·8	3 40·2	4 54·0	
			A 2.	5 33·3	4 15·0	4 54·1	
			A 1 L.	4 58·3	4 55·0	4 56·6	
			A 2 L.	5 07·3	4 47·3	4 57·3	
25.		3	A 1 L.	5 07·9	4 48·8	4 58·3	
			A 2.	4 35·4	5 10·3	4 52·8	4 55·5
				+	+	+	North.
Feb. 5.	Car Nicobar...	1	A 1.	1 20	1 13·2	1 16·6	
			A 1 L.	1 35·1	1 01·5	1 18·3	
			A 2 L.	1 21·8	1 11·8	1 16·8	
6.		2	A 1.	0 07·1	2 28·6	1 17·8	
			A 2.	0 39·0	2 00·3	1 19·6	
			A 1 L.	1 18·2	1 22·3	1 20·2	
			A 2 L.	1 08·7	1 23·8	1 16·2	
12.		3	A 2.	1 38·2	0 52·9	1 15·5	+
			A 1 L.	1 05·6	1 32	1 18·8	1 17·8
				—	—	—	South.
17.	Noncowry Harbour.	3	A 1 L.	1 13·8	0 44·1	0 58·9	—
			A 2.	0 38·8	1 13	0 55·9	0 57·4
19.	Bompoko......	3	A 1 L.	0 34·9	0 17·3	0 26·1	
			A 2	0 05·7	0 45·8	0 25·7	0 25·9
				+	+	+	+
Mar. 26.	Hastings' Island.	1	A 1.	4 30·5	4 35·0	4 32·7	North.
			A 1 L.	4 46·6	4 07·4	4 27·0	
			A 2 L.	4 38·7	4 22·6	4 30·6	
				+	+	+	North.
1849.							+
	Hastings' Island.	2	A 1.	3° 19′·8	5° 42′·3	4° 31′·0	
			A 2.	3 51·3	5 11·4	4 31·3	
			A 1 L.	4 46	4 26·9	4 36·9	
			A 2 L.	4 20·5	4 44·7	4 32·6	
		3	A 2.	4 51	4 16·7	4 33·8	
April 14.			A 1 L.	4 11	4 58	4 34·5	4° 32′·2
	Moulmein ...	2	A 1.	16 41·4	18 49·4	17 45·4	
17.			A 2.	17 06·0	18 24·8	17 45·4	
21.			A 1 L.	17 58	17 52·3	17 55·1	
		1	A 1.	17 53·9	17 42·7	17 48·3	
			A 1 L.	17 54·5	17 43·1	17 48·8	
24.			A 2 L.	17 51	17 41·7	17 46·3	
		3	A 2.	18 07·8	17 31·7	17 49·7	
May 23.			A 1 L.	17 37·7	18 10	17 53·8	17 49·1
	Madras	3	A 1 L.	7 16·0	7 59·1	7 37·5	
		1	A 1.	7 38·4	7 34·5	7 36·5	
		1	A 1 L.	7 41·8	7 35·5	7 38·6	
24.		1	A 2 L.	7 47·6	7 32·0	7 39·8	
26.		2	A 1.	6 24·9	8 43·0	7 34·0	
			A 2.	6 55·9	8 11·7	7 33·8	
			A 1.	6 24·9	8 48·3	7 36·6	
			A 1 L.	7 44·1	7 37·1	7 40·6	
			A 2 L.	7 25·6	7 50·7	7 38·1	
		3	A 2.	7 59·0	7 17·5	7 38·2	
July 24.			A 1 L.	7 27·5	7 57·3	7 42·4	
		2	A 1.	6 28·6	8 52·2	7 40·4	
			A 2.	6 55·7	8 17·8	7 36·7	
			A 1 L.	7 46·3	7 29·9	7 38·1	
27.			A 2 L.	7 27·2	7 51·2	7 39·2	
		1	A 1.	7 35·3	7 37·7	7 36·5	
28.			A 1 L.	7 41·8	7 28·8	7 35·3	
		1	A 1 L.	7 47·0	7 29·5	7 38·2	
		3	A 2.	7 59·5	7 14·5	7 38·0	
Aug. 30.		3	A 1 L.	7 25·5	7 56·7	7 41·1	
		1	A 1.	7 35·6	7 33·1	7 34·3	
		1	A 1 L.	7 37·6	7 29·7	7 33·6	
		1	A 2 L.	7 48·8	7 27·9	7 38·3	
		2	A 1.	6 23·1	8 48·1	7 35·6	
		2	A 2.	6 54·5	8 17·8	7 36·1	
		2	A 1 L.	7 25·0	7 54·8	7 39·9	
		2	A 2 L.	7 22·2	7 54·7	7 38·4	
		3	A 2.	8 00·8	7 19·8	7 40·3	
		3	A 1 L.	7 23·3	7 53·3	7 38·3	7 37·7

Table F.

General Table containing the mean result of all the Dips determined both on Shore and at Sea, and the whole reduced to one common Epoch, viz. January 1, 1848.

Station.	Date.	Latitude.	Longitude.	Dip observed.	Dip deduced, Jan. 1, 1848.	Place of observation.
Singapore	April, 1846	+1° 18′ 32″ N.	103° 56′ 30″ E.	−12° 47′·0 S.	−12° 51′·8 S.	Magnetic Observatory.
Singapore	March, 1848	....	....	12 56·8	12 56·2	Magnetic Observatory.
Singapore	January, 1849	....	....	12 59·4	12 56·7	Magnetic Observatory.
BORNEO.						
Sarāwak	July, 1846	1 33 54	110 29 00	11 10·9	11 14·9	Near Sir J. Brooke's House.
Sambas		1 22 00	109 28 00	11 27·0	11 31·0	Resident's Garden.
Permanket		1 10 29	109 04 15	12 31·8	12 35·8	Near the mouth of the River.
Pontiānak	August, 1846	−0 01 19 S.	109 30 00	14 41·3	12 45·0	Garden of the Resident.
Succadāna		1 15 33	109 57 00	16 58·4	17 02·1	Garden of Assistant Resident.
JAVA.						
Batavia	Sept. 1846	6 09 52	106 58 00	27 03·00	27 06·6	Magnetic Observatory in the middle of a large rice-field, termed Sāwa Besār.
Batavia	Nov. 1846	....	....	26 57·2	27 00·2	
Batavia		....	....	27 02·4	27 05·4	
Batavia	July, 1847	....	....	27 08·2	27 09·5	
Ceram	October, 1846	6 07 05	106 15 00	27 11·0	27 14·2	Garden of Resident.
Anjeer		6 02 47	106 01 00	26 28·8	26 32	Garden of Assistant Resident.
Cheringin		6 22 05	105 56 45	27 30·8	27 34	Garden of Assistant Resident.
Palambangan		6 31 00	105 54 45	28 05·4	28 08·6	Garden of Bungalow.
Chebiliang		6 47 00	105 49 15	28 37·9	28 41·1	Garden of Bungalow.
Chelangkahan		6 54 00	106 06 45	28 20·7	28 23·9	
Goonong Dādap		6 28 00?	106 06 00	27 28·5	27 31·7	Close to the Public Bungalow.
Woorong Goonong		6 11 00?	106 10 00?	27 20·0	27 23·2	Near the Assistant Resident's House.
Tanāra		6 08 00?	106 40 00?	27 02·6	27 05·8	Garden of Assistant Resident.
Tegu	December.	6 43 04	106 58 45	28 42·4	28 45·4	Garden of Bungalow.
Pangerango		6 51 00	106 59 00	29 42·7	29 45·7	Top of the Mountain near the Bungalow.
Chunjūr		6 50 08	107 09 45	28 23·1	28 26·1	Garden of Resident.
Kārang Tengga		6 58 16	106 47 45	28 21·1	28 24·1	Garden of Bungalow.
Chebrānok		6 57 14	106 25 30	28 27·8	28 30·8	Close to the River.
Wine Cooper's Bay		7 05 00?	106 36 00	29 18·5	29 21·5	Garden of Bungalow.
Chilotoe		7 11 17	106 27 00	28 51·3	28 54·3	Garden of Bungalow.
Pangangbahan		7 30 37	106 19 00	29 41·4	29 44·4	Garden of Bungalow.
Mooāro Chikasso		7 28 00	106 38 00	30 05·3	30 08·3	Garden of Bungalow.
Sidang Bārang		7 30 00	107 10 00	30 12·0	30 15·0	Garden of Bungalow.
Bejong Petair		7 13 36	107 02 00	29 33·5	29 36·5	Garden of Bungalow.
Bandong		6 55 44	107 40 30	28 31·4	28 34·4	Garden of Regent.
Garoet		7 13 54	107 55 00	28 58·5	29 01·5	Garden of Bungalow.
Permangpek		7 39 23	107 45 15	30 11·8	30 14·8	Garden of Bungalow.
Cherūgnūktok	January, 1847	7 38 25	108 09 45	30 08·2	30 10·9	Garden of Bungalow.
Kālipoochen		7 39 02	108 52 30	29 51·2	29 53·9	Garden of Assistant Resident.
Banjcer		7 23 08	108 42 00	29 07·2	29 09·9	Garden of Bungalow.
Chāwee		7 09 34	108 23 00	28 39·2	28 41·9	Garden of Bungalow.
Samadang		6 51 14	108 04 45	27 57·5	28 00·2	Garden of Inn.
Cheribon		6 43 34	108 42 00	27 49·3	27 52·0	Garden of Inn.
Indramāyu	February.	6 19 35	108 25 45	27 28·5	27 30·9	Garden of Assistant Resident.
Tegal		6 51 57	109 15 30	28 02·7	28 05·1	Garden of Inn.
Samārang		6 59 42	110 30 45	27 02·2	27 04·6	Mr. McLachlan's Garden.
Japara		6 36 07	110 38 15	27 27·5	27 29·9	Garden of Regent.
Ambarāwa		7 16 08	110 28 45	29 25·3	29 27·7	Garden of General Van der Wyck.
Balembang		7 24 00?	110 37 30	29 00·0	29 02·4	Garden of Mr. Forrestier.
Solo		7 35 00	110 53 30	29 10·3	29 12·7	Garden near the Inn.
Nyāwee	March.	7 23 52	111 29 15	28 57·7	28 59·9	Garden of Engineer Commandant.
Bankāwa		7 00 26	112 21 00	27 45·1	27 47·3	On the bank of the River Solo.
Soorabāya		7 16 01	112 44 30	28 50·8	28 53·0	Mr. Frazer's garden.
Sūmenap	April.	7 00 26	113 51 15	27 43·8	27 45·8	Ground in front of the Sultan's Palace.
Pulo Kuneeang		6 51 32	115 16 30	27 23·6	27 25·6	Garden of Bungalow.
Bczooki	May.	7 43 29	113 42 45	29 05·7	27 07·5	Garden of Resident.
Kedeeri		7 48 29	112 00 00	29 50·4	29 52·2	Garden of Resident.
Patchitan	June.	8 12 56	111 05 30	30 34·5	30 36	Garden of Resident.
Munoori		7 35 22	110 04 00	29 19·0	29 20·5	Garden of Bungalow.
Kārang Bolong		7 45 44	109 27 00	29 54·4	29 55·9	Garden of Bungalow.
Chilāchap		7 44 29	108 57 15	29 44·3	29 45·8	Garden of Bungalow.
Aji Bārang		7 24 49	109 03 30	27 20·8	27 22·1	Garden of Bungalow.
SUMATRA.						
Telok Betoug, Lampong Bay	September.	5 26 12	105 20 15	26 14·8	26 15·7	Garden of Assistant Resident.
Poolo Bay, near Bencoolen		3 53 54	102 28 45	23 53·1	23 54·0	Close to the Bay.
Padang	November.	0 58 58	100 31 15	18 31·7	18 32·2	Near the sea-shore.
Solok		0 47 05 S.	100 55 45 E.	17 53 S.	17 50·8 S.	Garden of Commandant.

TABLE F.

Station.	Date.	Latitude.	Longitude.	Dip observed.	Dip deduced, Jan. 1, 1848.	Place of observation.
SUMATRA.						
Sijonjong	Nov. 1847 …	−0° 41′ 47″ S.	101° 19′ 30″ E.	−17° 49′·3 S.	−17° 49′·8 S.	Garden of Commandant.
Bua Pānjāng		0 28 09	101 08 00	17 10·9	17 11·4	Garden of Commandant.
Pāyacombo		0 13 10	101 04 45	16 37·7	16 38·2	Garden of Commandant.
Fort Vande Capellen		0 27 34	101 03 00	17 11·8	17 12·3	Garden of Commandant.
Padang Panjang		0 22 00?	100 42 30	17 47·0	17 47·5	Garden of Inn.
Fort de Kock	December.	0 13 00?	100 27 15	16 59·4	16 59·6	Garden of Assistant Resident.
Menindjo		0 13 00?	100 14 00	17 00·4	17 00·6	Garden of Assistant Resident.
Balembangan		0 11 44	100 10 15	16 47·1	16 47·3	Garden of Assistant Resident.
Peesang		0 07 55	100 12 00	16 33·2	16 33·4	Garden of Bungalow.
Bonjol		0 00 52	100 13 00	16 38·3	16 38·5	Garden of Assistant Resident.
Loobisikapping		+0 06 55 N.	………	16 08·1	16 08·3	Garden of Controleur.
Batoo Bedindi		0 16 00	………	15 49·0	15 49·2	Garden of Bungalow.
Lender		0 24 24	100 04 00	15 35·0	15 35·2	Garden of Bungalow.
Rau		0 33 07	99 56 45	15 37·2	15 37·4	Garden of Assistant Resident.
Pionghay		0 36 19	99 52 15	15 50·0	15 50·2	Garden of Bungalow.
Batong		0 39 00	99 47 15	15 41·3	15 41·5	Garden of Bungalow.
Kotanopan		0 42 00	99 42 45	15 19·7	15 19·9	Garden of Bungalow.
Tāna Bātoo		0 44 26	99 30 45	15 02·9	15 03·1	Garden of Bungalow.
Fort Elout		0 50 56	99 32 20	14 47·9	14 48·1	Garden of Bungalow.
Singalāngan		1 14 48	………	14 11·7	14 11·9	Garden of Bungalow.
Padang Sidompang		1 22 33	99 22 45	13 46·8	13 47·0	Garden of Commandant.
Sibogha		1 44 42	98 56 15	13 02·3	13 02·5	Garden of Resident.
Bāros		2 00 51	98 31 30	12 57·8	12 58·0	Garden of Assistant Resident.
Sinkel		2 16 37	97 51 35	12 23·3	12 23·5	Garden of Commandant.
Pulonias, Goonong Satoolie	Jan. 1848……	1 17 35	97 40 30	14 05·6	14 05·8	Garden of Commandant.
Nātal		0 33 44	99 20 15	15 32·2	15 32·4	Garden of Assistant Resident.
Mount Ophir, near Malācca	April 1848 …	2 22 ?	102 38 ?	9 55·8	9 55·1	Top of Mount Ophir.
At sea	Apr. 25.	2 20	107 11	9 56·8	9 56·1	At sea.
At sea	Apr. 26.	2 17	107 49	9 25·6	9 24·9	At sea.
At sea	Apr. 27.	2 42	108 03	9 57·4	9 56·7	At sea.
At sea	Apr. 28.	2 48	109 25	8 39·8	8 39·1	At sea.
At sea	Apr. 29.	3 19	111 18	7 17·0	7 16·3	At sea.
At sea	May 1.	4 45	113 45	4 06·6	4 05·6	At sea.
	May 2.	5 16	115 16	2 53·7	2 52·7	At sea.
Pulo Labooan	May.	5 16 59	115 18 15	2 52·6	2 51·6	Near the flag-staff.
At sea	May 11.	5 41	115 05	1 33·1	1 32·1	At sea.
At sea	May 12.	6 23	116 09	+ 0 03·7 N.	+ 0 02·7 N.	At sea.
At sea	May 13.	7 25	117 18	1 46·6	1 45·6	At sea.
At sea	May 14.	7 11	118 44	1 32·6	1 31·6	At sea.
At sea	May 15.	7 07	119 50	1 34·3	1 33·3	At sea.
At sea	May 16.	7 15	120 30	1 33·8	1 32·8	At sea.
At sea	May 17.	7 13	120 44	1 26·8	1 25·8	At sea.
At sea	May 18.	6 54	121 30	0 37·4	0 36·4	At sea.
At sea	May 19.	7 03	121 18	0 50·6	0 49·6	At sea.
At sea	May 20.	7 09	121 50	0 57·7	0 56·7	At sea.
Sambooanga	June.	6 54 20	122 13 45	1 19·3	1 18·2	On the spot where Sir E. Belcher observed.
At sea	June 3.	6 25	122 44	− 0 25·0 S.	− 0 23·9 S.	
At sea	June 5.	5 19	125 03	2 34·5	2 33·4	At sea.
At sea	June 6.	4 24	124 00	4 14·5	4 13·4	At sea.
At sea	June 7.	3 56	124 40	5 17·2	5 16·1	At sea.
At sea	June 8.	3 34	124 20	5 42·6	5 41·6	At sea.
At sea	June 9.	3 37	125 20	5 50·4	5 49·3	At sea.
At sea	June 10.	3 20	125 00	6 22·2	6 21·1	At sea.
At sea	June 11.	3 02	125 21	6 56·6	6 55·5	At sea.
At sea	June 12.	2 26	125 24	8 18·0	8 16·9	At sea.
At sea	June 13.	1 59	125 27	8 54·0	8 52·9	At sea.
At sea	June 14.	1 47	125 27	9 44	9 42·9	At sea.
At sea	June 15.	1 34	125 21	9 57·1	9 56·0	At sea.
Keemah	July.	1 21 55	125 07 59	11 02·7	11 01·4	In a garden near the village.
Tondāno	July.	1 17 31	124 59 11	10 55·6	10 54·3	Garden of Missionary.
Manādo	July.	1 29 11	124 51 11	10 44·9	10 43·6	Garden near the fort.
At sea	July 7.	0 38 51	126 29	11 48·8	11 47·5	At sea.
At sea	July 8.	0 26 52	127 05	12 44·5	12 43·2	At sea.
At sea	July 10.	−0 11 S.	128 42	13 51·2	13 49·9	At sea.
At sea	July 11.	0 33	127 55	14 24·5	14 23·2	At sea.
At sea	July 12.	1 25	128 00	16 42·1	16 40·8	At sea.
At sea	July 13.	1 32	128 05	16 33·1	16 31·8	At sea.
At sea	July 14.	1 29	128 12	16 48·7	16 47·4	At sea.
At sea	July 15.	2 13	127 57	17 28·3	17 27·0	At sea.
At sea	July 17.	2 55	126 00	19 14·5	19 13·2	At sea.
At sea	July 21.	4 20	123 10	22 21·7	22 20·4	At sea.
At sea	July 22.	5 05	122 30	23 39·6	23 38·3	At sea.
At sea	July 24.	5 46	121 03	25 03·5	25 02·2	At sea.
At sea	July 25.	5 51	−119 36	25 18·3	25 17·0	At sea.

Table F.

Station.	Date.	Latitude.	Longitude.	Dip observed.	Dip deduced, Jan. 1, 1848.	Place of observation.
SUMATRA.						
At sea	July 28, 1848	– 5° 34′ ″ S.	112° 20′ ″ E.	–25° 26′·1 S.	- 25° 24′·8 S.	At sea.
At sea	July 29.	5 30	110 12	25 21·1	25 19·8	At sea.
At sea	July 31.	5 58	106 55	26 24·1	26 22·8	At sea.
At sea	Aug. 12.	6 10	107 04	26 47·8	26 46·3	At sea.
At sea	Aug. 16.	6 04	105 27	26 32·0	26 30·5	At sea.
At sea	Aug. 17.	6 32	105 00	27 29·7	27 28·2	At sea.
At sea	Aug. 20.	6 35	104 45	27 36·7	27 35·2	At sea.
Cocos or Keeling Island	September.	12 05 38	96 50 30	39 20·0	39 18·5	Cocoa Nut Plantation, Direction [Island.
At sea	Oct. 4.	6 12	103 30	27 03·6	27 01·6	At sea.
At sea	Oct. 5.	5 38	103 17	25 40·3	25 38·3	At sea.
At sea	Oct. 22.	5 23	106 37	24 58 5	24 56·5	At sea.
At sea	Oct. 23.	3 24	105 58	21 46·7	21 44·7	At sea.
At sea	Oct. 24.	3 12	105 45	20 58·0	20 56·0	At sea.
At sea	Oct. 25.	2 51	105 38	20 23·2	20 21·2	At sea.
At sea	Oct. 26.	2 17	105 29	19 38·6	19 36·6	At sea.
At sea	Oct. 27.	2 06	104 44	19 19·9	19 17·9	At sca.
At sea	Oct. 30.	1 39	104 32	18 17·0	18 15·0	At sea.
At sea	Oct. 31.	1 23	105 07	17 59·8	17 57·8	At sea.
At sea	Nov. 1.	1 11	105 00	17 36·0	17 34·0	At sea.
At sea	Nov. 3.	+ 0 46 N.	105 20	14 03·2	14 01·0	At sea.
At sea	Nov. 4.	1 08	105 20	12 58·9	12 56·7	At sea.
At sea	Nov. 5.	1 16	103 55	13 15·2	13 13·0	At sea.
At sea	Jan. 1, 1849	1 40	102 51	12 04·1	12 01·4	At sea.
Malacca	Jan. 2.	2 11 19	102 17 00	11 27·9	11 25·2	Near the fort.
At sea	Jan. 4.	2 10	102 15	11 27·3	11 24·6	At sea.
At sea	Jan. 8.	3 54	100 25	7 44	7 41·3	At sea.
Pulo Dinding	January.	4 12 47	100 32 52	7 33·9	7 31·2	On the sea-shore.
Pulo Penang	February.	5 25 36	100 24 38	4 55·5	4 52·8	To the north and westward of Fort [Cornwallis.
At sea	Feb. 1.	7 53	97 13	0 03·3	0 00·3	At sea.
Car Nicobar	February.	9 10 12	92 48 23	+ 1 17·8 N.	+ 1 14·8 N.	On the sea-shore.
Noncowry Harbour		8 01 42	93 39 20	– 0 57·4 S.	– 0 54·4 S.	On an elevation near the shore.
Bompoko		8 14 05	93 19 20	0 25·9	0 22·9	In the village.
At sea	Mar. 19.	6 59	98 30	1 31·2	1 28·0	At sea.
At sea	Mar. 20.	8 06	97 34	+ 0 31·2 N.	+ 0 28·0 N.	At sea.
At sea	Mar. 21.	8 40	97 52	1 24·1	1 20·9	At sea.
At sea	Mar. 22.	9 11	98 10	2 49·0	2 45·8	At sca.
At sea	Mar. 23.	9 46	98 16	3 54·8	3 51·6	At sea.
Hastings' Island	Mar. 26.	10 06 45	98 21 15	4 22·2	4 19·0	On the sea-shore.
At sea	Mar. 29.	10 22	97 44	4 36·8	4 33·6	At sea.
At sea	Mar. 30.	11 01	97 30	5 52·2	5 49·0	At sea.
At sea	Mar. 31.	11 21	97 17	6 52·0	6 48·8	At sea.
At sea	April 2.	12 17	97 35	8 43·2	8 39·7	At sea.
At sea	April 3.	12 25	97 34	9 00·7	8 57·2	At sea.
At sea	April 5.	14 44	97 21	13 47·7	13 44·2	At sea.
At sea	April 6.	15 07	97 26	14 51·6	14 48·1	At sea.
At sea	April 7.	16 04	97 34	17 12·7	17 09·2	At sea.
Moulmein	April,	16 29 46	97 45 30	17 49·1	17 45·6	Garden of Captain Scott.
Madras	May,	13 04 09	80 16 00	7 37·7	7 34·2	Garden of Observatory.

TABLE G.

Absolute Horizontal Intensity at various Stations in the Eastern Archipelago, from observations made with the Induction Inclinometer, with the Observatory Unifilar Magnetometer, and with JONES'S Portable Unifilar Magnetometer.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1846.					° ′ ″	seconds.				
Mar. 20.	Singapore.	H 12	D 5	1·20	2 34 00	1158·0	O	0·316	8·135	
				1·30	2 01 03			0·316	8·140	
				1·40	1 36 56			0·316	8·141	
				1·60	1 04 56			0·316	8·144	
				1·70	0 54 13			0·316	8·138	
				1·80	0 45 37			0·316	8·144	
				1·90	0 38 57			0·317	1·128	
				2·00	0 33 18			0·316	8·139	
				2·20	0 24 58			0 316	8·148	
		H 12	D 6	1·20	2 29 20	1170·4		0·306	8·112	
				1·30	1 57 32			0·306	8·121	
				1·40	1 34 01			0·305	8·127	
				1·50	1 16 26			0·306	8·119	
				1·60	1 03 02			0·306	8·116	
		H 12	D 6	1·70	0 52 38	1170·4		0·306	8·110	
				1·80	0 44 26			0·306	8·102	
				1·90	0 37 27			0·306	8·120	
				2·00	0 32 10			0·305	8·131	
				2·10	0 27 54			0 306	8·115	
				2·20	0 24 15			0·306	8·118	
				2·30	0 21 10			0·305	8·129	
28.		H 12	D 5	1·25	2 16 41	1158·0		0·317	8·133	
				1·30	2 01 31			0·316	8·133	
				1·35	1 48 30			0·316	8·136	
				1·40	1 37 13			0·316	8·139	
31.		H 11	D 5	1·25	2 17 40	1158·0	1.	0·318	8·098	
				1·30	2 02 20			0·318	8·101	
				1·35	1 49 10			0·318	8·105	
				1·40	1 37 55			0·318	8·104	
		H 11	D 6	1·25	2 12 22	1170·4		0·306	8·111	
				1·30	1 57 32			0·306	8·116	
				1·35	1 45 05			0·306	8·112	
				1·40	1 34 11			0·306	8·115	
April 1.		H 12	D 6	1·25	2 11 32		O.	0·305	8·134	
				1·30	1 57 02			0·305	8·132	
				1·35	1 44 33			0·305	8·131	
				1·40	1 33 40			0·305	8·135	
2.		H 11	A 8	1·15	2 10 19	1020·9		0·236	8 133	
				1·40	1 12 26			0·236	8·133	
3.		H 11	A 10	1·25	2 15 52	889·4		0·315	8·100	
				1·40	1 36 49			0·315	8·101	
		H 12	A 10	1·25	2 15 01			0·314	8·114	
				1·40	1 36 17			0·314	8·111	
11.		H 12	A 6	1·20	2 13 43	949·2		0·276	8·129	
				1·40	1 24 28			0·276	8·133	
				1·20	2 14 46		1.	0·276	8·110	
				1·40	1 25 16			0·277	8·097	
		H 12	A 9	1·30	2 02 57	869·46	O.	0·321	8·108	
				1·40	1 38 30			0·320	8·117	
13.		H 11	A 9	1·30	2 03 45	868·10	I.	0·321	8·105	
				1·40	1 39 09			0·321	8·103	
		H 11	A 7	1·30	2 15 54	840·5		0·354	8·103	
				1·40	1 48 39			0·353	8·112	
		H 12	A 7	1·30	2 15 08		O.	0·353	8·118	
				1·40	1 48 16			0·353	8·116	8·121
1848.										
Feb. 18.		H 11	D 5	1·25	2 07 47	1202·5	1.	0·294	8·107	
				1·30	1 53 35			0·294	8·108	
				1·35	1 41 20			0·294	8·109	
				1·40	1 30 49			0·294	8·114	
		H 11	A 7	1·30	2 09 25	861·0		0·336	8·095	
				1·35	1 55 40			0·336	8·094	
				1·40	1 43 50			0·337	8·090	
				1·45	1 33 36			0·337	8·089	
		H 11	A 8	1·15	1 59 37	1064·7		0·216	8 127	
				1·20	1 45 20			0·216	8·124	
1848.					° ′ ″	seconds.				
Feb. 18.	Singapore.	H 11	A 8	1·25	1 33 12	1064·7	1.	0·216	8·131	
				1·30	1 22 59			0·217	8·124	
		H 11	A 9	1·25	2 14 59	881·4		0·312	8·105	
				1·30	2 00 03			0·312	8·108	
				1·35	1 47 13			0 312	8·109	
				1·40	1 36 14			0·312	8·105	
		H 11	A 10	1·25	1 58 39	951·3		0·274	8·113	
				1·30	1 45 27			0·274	8·116	
				1·35	1 34 10			0·274	8·117	
				1·40	1 24 29			0·274	8·115	
Mar. 7.		H 12	D 5	1·25	2 07 05	1202·5	O.	0·294	8·124	
				1·30	1 52 53			0·293	8·130	
				1·35	1 40 44			0·293	8·132	
				1·40	1 30 22			0·293	8·131	
		H 12	A 7	1·30	2 08 44	861·0		0·336	8·113	
				1·35	1 54 58			0·336	8·114	
				1·40	1 43 12			0·336	8·111	
				1·45	1 32 48			0·335	8·116	
		H 12	A 8	1·15	1 59 09	1064·7		0·216	8·135	
				1·20	1 45 06			0·216	8·130	
				1·25	1 32 53			0·216	8·142	
				1·30	1 22 35			0·216	8·140	
		H 12	A 9	1·25	2 14 22	881·4		0·312	8·101	
				1·30	1 59 38			0·312	8·099	
				1·35	1 46 53			0·312	8·099	
				1·40	1 35 48			0·312	8·103	
		H 12	A 10	1·25	1 58 19	951·3		0·275	8·094	
				1·30	1 45 07			0·275	8·102	
				1·35	1 33 54			0·275	8·102	
				1·40	1 24 16			0·275	8·100	
Feb. 19.		H 11	D 5	1·25	2 06 58	1202·5	1.	0·293	8·132	
				1·30	1 55 02			0·293	8·126	
				1·35	1 46 50			0·293	8·131	
				1·40	1 30 20			0·293	8·134	
		H 11	A 7	1·30	2 09 08	861·0		0·336	8·101	
				1·35	1 55 13			0·336	8·107	
				1·40	1 43 20			0·336	8·107	
				1·45	1 32 58			0·336	8·110	
		H 11	A 8	1·15	1 59 23	1064·7		0·216	8·127	
				1·20	1 45 12			0·216	8·126	
				1·25	1 33 10			0·216	8·130	
				1·30	1 22 52			0·216	8·126	
		H 11	A 9	1·25	2 14 29	881·4		0·311	8·121	
				1·30	1 59 25			0·311	8·128	
				1·35	1 46 44			0·311	8·124	
				1·40	1 35 47			0·311	8·121	
		H 11	A 10	1·25	1 58 26	951·3		0·274	8·119	
				1·30	1 45 23			0·274	8·117	
				1·35	1 34 07			0·274	8·117	
				1·40	1 24 26			0·274	8·115	
Mar. 8.		H 12	D 5	1·25	2 06 50	1202·5	O.	0·293	8·134	
				1·30	1 52 44			0·293	8·137	
				1·35	1 40 41			0·293	8·137	
		H 12	A 7	1·30	2 08 50	861·0		0·336	8·112	
				1·35	1 55 09			0·336	8·111	
				1·40	1 43 20			0·336	8·108	
				1·45	1 32 59			0·334	8·111	
		H 12	A 8	1·15	1 58 48	1064·7		0·216	8·149	
				1·20	1 44 57			0·216	8·138	
				1·25	1 32 54			0·216	8·143	
				1·30	1 22 32			0·216	8·145	
		H 12	A 9	1·25	2 14 17	881·4		0·312	8·099	
				1·30	1 59 21			0·312	8·099	
				1·35	1 46 38			0·312	8·108	
				1·40	1 35 35			0·312	8·111	
		H 12	A 10	1·25	1 58 17	951·3		0·275	8·094	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1848.					° ′ ″	seconds.				
Mar. 9.	Singapore.	H 12	A 10	1·30	1 45 10	951·3	O.	0·275	8·098	
				1·35	1 33 56			0·275	8·100	
				1·40	1 24 26			0·275	8·091	
Feb. 21.		H 11	D 5	1·25	2 07 20	1202·5	I.	0·294	8·118	
				1·30	1 53 08			0·294	8·121	
				1·35	1 41 01			0·294	8·121	
				1·40	1 30 52			0·294	8·108	
		H 11	A 7	1·30	2 09 12	861·0		0·336	8·098	
				1·35	1 55 23			0·336	8·100	
				1·40	1 43 32			0·336	8·100	
				1·45	1 33 16			0·336	8·095	
		H 11	A 8	1·15	1 59 41	1064·7		0·217	8·116	
				1·20	1 45 32			0·217	8·113	
				1·35	1 33 22			0·217	8·120	
				1·40	1 23 01			0·217	8·118	
		H 11	A 9	1·25	2 14 50	881·4		0·312	8·110	
				1·30	1 59 53			0·312	8·113	
				1·35	1 47 05			0·312	8·111	
				1·40	1 36 02			0·312	8·111	
		H 11	A 10	1·25	1 58 39	951·3	I.	0·274	8·111	
				1·30	1 45 29			0·274	8·113	
				1·35	1 34 12			0·274	8·113	
				1·40	1 24 31			0·274	8·111	
Mar. 10.		H 12	D 5	1·25	2 06 32	1202·5	O.	0·293	8·141	
				1·30	1 52 47			0·293	8·133	
				1·35	1 40 23			0·293	8·147	
				1·40	1 30 05			0·293	8·141	
		H 12	A 7	1·30	2 08 39	861·0		0·335	8·115	
				1·35	1 54 54			0·335	8·117	
				1·40	1 43 23			0·336	8·104	
				1·45	1 32 52			0·336	8·113	
		H 12	A 8	1·15	1 59 01	1064·7		0·216	8·139	
				1·20	1 44 49			0·216	8·140	
				1·25	1 32 48			0·216	8·145	
				1·30	1 22 25			0·216	8·148	
13.		H 12	A 9	1·25	2 14 12	881·4		0·312	8·107	
				1·30	1 59 17			0·312	8·111	
				1·35	1 46 39			0·312	8·108	
				1·40	1 35 41			0·312	8·108	
		H 12	A 10	1·25	1 57 54	951·3		0·274	8·108	
				1·30	1 44 50			0·274	8·112	
				1·35	1 33 40			0·274	8·112	
				1·40	1 24 01			0·274	8·106	
Feb. 22.		H 11	D 5	1·25	2 07 21	1202·5	I.	0·294	8·118	
				1·30	1 53 09			0·294	8·120	
				1·35	1 41 01			0·294	8·121	
				1·40	1 30 46			0·294	8·112	
		H 11	A 7	1·30	2 09 16	861·0		0·336	8·095	
				1·35	1 55 31			0·336	8·094	
				1·40	1 43 38			0·336	8·093	
				1·45	1 33 14			0·336	8·096	
		H 11	A 8	1·15	1 59 46	1064·7		0·217	8·113	
				1·20	1 45 25			0·217	8·117	
				1·25	1 33 23			0·217	8·119	
				1·30	1 23 00			0·217	8·114	
		H 11	A 9	1·25	2 15 00	881·4		0·312	8·106	
				1·30	2 00 08			0·312	8·103	
				1·35	1 47 20			0·312	8·108	
				1·40	1 36 16			0·312	8·101	
		H 11	A 10	1·25	1 58 47	951·3		0·274	8·107	
				1·30	1 45 37			0·274	8·108	
				1·35	1 34 19			0·274	8·109	
				1·40	1 24 41			0·274	8·104	
Mar. 14.		H 12	D 5	1·25	2 06 39	1202·5	O.	0·293	8·137	
				1·30	1 52 43			0·293	8·136	
				1·35	1 40 46			0·293	8·134	
				1·40	1 30 10			0·293	8·139	
		H 12	A 7	1·30	2 08 31	861·0		0·335	8·118	
				1·35	1 54 56			0·336	8·113	
				1·40	1 43 07			0·336	8·112	
1848.					° ′ ″	seconds.				
Mar. 14.	Singapore.	H 12	A 7	1·45	1 32 41	861·0	O.	0·335	8·119	
		H 12	A 8	1·15	1 59 00	1064·7		0·216	8·139	
				1·20	1 44 38			0·216	8·147	
				1·25	1 32 44			0·216	8·148	
				1·30	1 22 28			0·216	8·145	
		H 12	A 9	1·25	2 14 03	881·4		0·312	8·110	
				1·30	1 59 11			0·312	8·112	
				1·35	1 46 27			0·311	8·114	
				1·40	1 35 28			0·311	8·115	
17.		H 12	A 10	1·25	1 58 13	951·3		0·275	8·096	
				1·30	1 45 04			0·275	8·102	
				1·35	1 33 34			0·274	8·116	
				1·40	1 24 08			0·274	8·106	
Feb. 23.		H 11	D 5	1·25	2 07 05	1202·5	I.	0·293	8·129	
				1·30	1 52 55			0·293	8·131	
				1·35	1 40 52			0·293	8·130	
				1·40	1 30 15			0·293	8·129	
		H 11	A 7	1·30	2 08 56	861·0		0·336	8·111	
				1·35	1 55 14			0·336	8·109	
				1·40	1 43 29			0·336	8·104	
				1·45	1 33 00			0·336	8·110	
24.		H 11	A 8	1·15	1 59 29	1064·7		0·216	8·126	
				1·20	1 45 22			0·217	8·122	
				1·25	1 33 18			0·216	8·126	
				1·30	1 22 48			0·216	8·132	
		H 11	A 9	1·25	2 15 01	881·4	I.	0·312	8·106	
				1·30	2 00 02			0·312	8·108	
				1·35	1 47 03			0·311	8·114	
				1·40	1 36 03			0·312	8·112	
		H 11	A 10	1·25	1 58 37	951·3		0·274	8·114	
				1·30	1 45 31			0·274	8·113	
				1·35	1 34 04			0·274	8·120	
				1·40	1 24 29			0·274	8·114	
Mar. 10.		H 12	D 5	1·25	2 06 38	1202·5	O.	0·293	8·137	
				1·30	1 52 33			0·293	8·140	
				1·35	1 40 34			0·293	8·138	
				1·40	1 30 08			0·293	8·140	
		H 12	A 7	1·30	2 09 01	861·0		0·336	8·101	
				1·35	1 55 22			0·336	8·097	
				1·40	1 43 20			0·336	8·102	
				1·45	1 32 56			0·336	8·107	
		H 12	A 8	1·15	1 58 55	1064·7		0·216	8·141	
				1·20	1 44 48			0·216	8·140	
				1·25	1 32 49			0·216	8·143	
				1·30	1 22 31			0·216	8·142	
		H 12	A 9	1·25	2 14 10	881·4		0·312	8·109	
				1·30	1 59 26			0·312	8·107	
				1·35	1 46 40			0·312	8·108	
				1·40	1 35 45			0·312	8·106	
		H 12	A 10	1·25	1 58 19	951·3		0·275	8·096	
				1·30	1 45 11			0·275	8·100	
				1·35	1 34 00			0·275	8·099	
				1·40	1 24 11			0·274	8·106	8·116
Nov. 16.		H 11	D 5	1·25	2 04 47	1215·9	I.	0·288	8·114	
				1·30	1 50 59			0·288	8·113	
				1·35	1 39 04			0·288	8·114	
				1·40	1 28 47			0·287	8·116	
17.		H 11	A 7	1·30	2 06 41	867·7		0·331	8·127	
				1·35	1 53 13			0·331	8·125	
				1·40	1 41 38			0·331	8·122	
				1·45	1 31 36			0·331	8·117	
		H 11	A 8	1·15	1 55 17	1085·3		0·208	8·098	
				1·20	1 41 31			0·208	8·099	
				1·25	1 29 57			0·208	8·097	
				1·30	1 19 54			0·208	8·103	
25.		H 11	A 9	1·25	2 13 14	886·7		0·308	8·109	
				1·30	1 58 17			0·308	8·116	
				1·35	1 45 46			0·308	8·111	
				1·40	1 34 52			0·308	8·110	
		H 11	A 10	1·25	1 57 20	956·8		0·271	8·104	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1848.					° ′ ″	seconds.				
Nov. 25.	Singapore.	H 11	A 10	1·30	1 44 19	956·8	I.	0·271	8·105	
				1·35	1 33 09			0·271	8·106	
				1·40	1 23 33			0·271	8·105	
16.		B.	D 5	1·05	3 29 31	1215·9	J.	0·287	8·121	
				1·10	3 02 16			0·287	8·122	
				1·15	2 39 26			0·287	8·125	
				1·20	2 20 33			0·287	8·120	
				1·25	2 04 06			0·287	8·129	
				1·30	1 50 26			0·287	8·126	
				1·35	1 38 41			0·287	8·123	
				1·40	1 28 29			0·287	8·123	
		B.	A 7	1·10	3 27 46	867·7		0·331	8·114	
				1·15	3 02 04			0·331	8·114	
				1·20	2 40 20			0·331	8·117	
				1·25	2 22 01			0·331	8·117	
				1·30	2 09 14			0·331	8·119	
				1·35	1 52 53			0·331	8·119	
				1·40	1 41 16			0·331	8·119	
				1·45	1 31 10			0·331	8·120	
		B.	A 8	0·95	3 22 50	1085·3		0·208	8·119	
				1·00	2 54 06			0·208	8·119	
				1·05	2 30 25			0·208	8·123	
				1·10	2 11 01			0 208	8·121	
				1·15	1 54 50			0·208	8·117	
				1·20	1 41 08			0·208	8·118	
				1·25	1 29 32			0·208	8·117	
				1·30	1 19 36			0·208	8·119	
		B.	A 9	1·05	3 43 46	886·7		0·309	8·088	
				1·10	3 14 55			0·309	8·088	
				1·15	2 50 46			0·309	8·088	
				1·20	2 30 15			0·308	8·092	
				1·25	2 13 07			0·309	8·077	
				1·30	1 58 19			0·309	8·083	
				1·35	1 45 45			0·309	8·083	
				1·40	1 34 52			0·309	8·084	
17.		B.	A 10	1·05	3 16 06	956·8		0·271	8·097	
				1·10	2 50 42			0·271	8·099	
				1·15	2 29 30			0·271	8·101	
				1·20	2 11 45			0·271	8·100	
				1·25	1 56 37			0·271	8·101	
				1·30	1 43 43	956·8		0·271	8·103	
				1·35	1 32 44			0·271	8·101	
				1·40	1 23 08			0·271	8·104	
		H 12	D 5	1·05	3 29 38	1215·9	O.	0·287	8·118	
				1·10	3 02 02			0·287	8·126	
				1·15	2 39 16			0·287	8·128	
				1·20	2 20 09			0·287	8·128	
				1·25	2 04 01			0·287	8·130	
				1·30	1 50 15			0·287	8·131	
				1·35	1 38 27			0·287	8·132	
				1·40	1 28 16			0·287	8·132	
		H 12	A 7	1·10	3 28 25	867·7		0·332	8·099	
				1·15	3 02 25			0·332	8·104	
				1·20	2 40 30			0·331	8·111	
				1·25	2 22 09			0·331	8·114	
				1·30	2 06 19			0·331	8·117	
				1·35	1 52 49			0·331	8·119	
				1·40	1 41 16			0·331	8·117	
				1·45	1 31 07			0·331	8·121	
18.		H 12	A 8	0·95	3 22 28	1085·3		0·207	8·125	
				1·00	2 53 42			0·207	8·128	
				1·05	2 30 05			0·207	8·131	
				1·10	2 10 45			0·207	8·128	
				1·15	1 54 28			0·207	8·129	
				1·20	1 40 38			0·207	8·137	
				1·25	1 29 08			0·207	8·135	
				1·30	1 19 04			0·207	8·137	
		H 12	A 9	1·05	3 43 58	886·7		0·309	8·084	
				1·10	3 14 48			0·309	8·089	
				1·15	2 50 40			0·309	8·089	
1848.					° ′ ″	seconds.				
Nov. 18.	Singapore.	H 12	A 9	1·20	2 30 07	886·7	O.	0·308	8·095	
				1·25	2 12 52			0·309	8·084	
				1·30	1 58 11			0·309	8·086	
				1·35	1 45 34			0·309	8·088	
				1·40	1 34 45			0·309	8·088	
		H 12	A 10	1·05	3 16 23	956·8		0·271	8·090	
				1·10	2 50 48			0·271	8·096	
				1·15	2 29 32			0·271	8·099	
				1·20	2 11 46			0·271	8·099	
				1·25	1 56 41			0·271	8·098	
				1·30	1 43 45			0·271	8·101	
				1 35	1 32 39			0·271	8·103	
				1·40	1 23 12			0·271	8·101	
Dec. 1.		H 11	D 5	1·25	2 04 44	1215·9	I.	0·287	8·117	
				1·30	1 50 53			0·287	8·117	
				1·35	1 38 59			0·288	8·118	
				1·40	1 28 38			0·287	8·124	
		H 11	A 7	1·30	2 07 00	867·7		0·331	8·121	
				1·35	1 53 26			0·331	8·122	
				1·40	1 41 48			0·332	8·120	
				1·45	1 31 41			0·331	8·118	
		H 11	A 8	1·15	1 55 02	1085·3		0·208	8·110	
				1·20	1 41 20			0·208	8·110	
				1·25	1 29 47			0·208	8·108	
				1·30	1 19 53			0·208	8·107	
2.		H 11	A 9	1·25	2 13 36	886·7		0·308	8·100	
				1·30	1 58 48			0·308	8·100	
				1·35	1 46 07			0·308	8·100	
				1·40	1 35 14			0·308	8·097	
		H 11	A 10	1·25	1 57 25	956·8		0·271	8·104	
				1·30	1 44 24			0·271	8·104	
				1·35	1 33 15			0·271	8·104	
				1·40	1 23 41			0·271	8·101	
1.		B.	D 5	1·05	3 29 07	1215·9	J.	0·287	8·131	
				1·10	3 01 59			0·287	8·130	
				1·15	2 39 08			0·287	8·135	
				1·20	2 20 12			0·287	8·132	
				1·25	2 04 02			0·287	8·133	
				1·30	1 50 14			0·287	8·135	
				1·35	1 38 28			0·287	8·135	
				1·40	1 28 30			0·287	8·125	
4.		B.	A 7	1·10	3 27 58	867·7		0·331	8·111	
				1·15	3 02 14			0·331	8·112	
				1·20	2 40 46			0·332	8·107	
				1·25	2 22 02			0·331	8·117	
				1·30	2 06 24			0·331	8·117	
				1·35	1 52 51			0·331	8·121	
				1·40	1 41 17			0·331	8·120	
				1·45	1 31 08			0·331	8·124	
10.		B.	A 8	0·95	3 22 22	1085·3		0·207	8·129	
				1·00	2 53 48			0·207	8·127	
				1·05	2 30 13			0·207	8·129	
				1·10	2 10 39			0·207	8·133	
				1·15	1 54 37			0·207	8·126	
				1·20	1 40 59			0·208	8·124	
				1·25	1 29 25			0·208	8·123	
				1·30	1 19 29			0·207	8·126	
4.		B.	A 9	1·05	3 43 01	886·7		0·308	8·101	
				1·10	3 14 09			0·308	8·102	
				1·15	2 50 05			0·308	8·102	
				1·20	2 29 43			0·308	8·106	
				1·25	2 12 33			0·308	8·093	
				1·30	1 57 54			0·308	8·095	
				1·35	1 45 24			0·308	8·095	
				1·40	1 34 35			0·308	8·094	
6.		B.	A 10	1·05	3 16 21	956·8		0·271	8·091	
				1·10	2 50 57			0·271	8·093	
				1·15	2 29 46			0·271	8·093	
				1·20	2 11 50			0·271	8·097	
				1·25	1 56 40			0·271	8·099	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1848.					° ′ ″	seconds.				
Dec. 6.	Singapore.	B.	A 10	1·30	1 43 52	956·8	J.	0·271	8·097	
				1·35	1 32 52			0·271	8·094	
				1·40	1 23 10			0·271	8·101	
		H 12	D 5	1·05	3 29 19	1215·9	O.	0·287	8·124	
				1·10	3 02 01			0·287	8·127	
				1·15	2 39 05			0·287	8·133	
				1·20	2 20 03			0·287	8·133	
				1·25	2 03 53			0·287	8·135	
				1·30	1 50 11			0·287	8·134	
				1·35	1 38 23			0·287	8·134	
				1·40	1 28 10			0·287	8·137	
		H 12	A 7	1·10	3 28 27	867·7		0·332	8·100	
				1·15	3 02 36			0·332	8·106	
				1·20	2 40 30			0·331	8·112	
				1·25	2 22 05			0·331	8·114	
				1·30	2 06 25			0·331	8·115	
				1·35	1 52 58			0·331	8·115	
				1·40	1 41 18			0·331	8·117	
				1·45	1 31 08			0·331	8·122	
		H 12	A 8	0·95	3 22 25	1085·3		0·207	8·131	
				1·00	2 53 22			0·207	8·140	
				1·05	2 30 02			0·207	8·138	
				1·10	2 10 29			0·207	8·141	
				1·15	1 54 20			0·207	8·139	
				1·20	1 40 47			0·207	8·136	
				1·25	1 29 11			0·207	8·137	
				1·30	1 19 22			0·207	8·135	
7.		H 12	A 9	1·05	3 43 17	886·7		0·308	8·096	
				1·10	3 14 20			0·308	8·099	
				1·15	2 50 04			0·308	8·103	
				1·20	2 29 48			0·308	8·104	
				1·35	2 12 36			0·308	8·092	
				1·30	1 57 52			0·308	8·097	
				1·35	1 45 17			0·308	8·100	
				1·40	1 34 28			0·308	8·100	
		H 12	A 10	1·05	3 16 05	956·8		0·271	8·096	
				1·10	2 50 36			0·271	8·101	
				1·15	2 29 29			0·271	8·100	
				1·20	2 11 23			0·271	8·101	
				1·25	1 56 37			0·271	8·100	
				1·30	1 43 42			0·271	8·103	
				1·35	1 32 40			0·271	8·102	
				1·40	1 23 08			0·271	8·102	
21.		H 11	D 5	1·25	2 04 18	1215·5	I.	0·287	8·130	
				1·30	1 50 31			0·287	8·131	
				1·35	1 38 42			0·287	8·130	
				1·40	1 28 32			0·287	8·129	
		H 11	A 7	1·30	2 06 46	868·7		0·331	8·108	
				1·35	1 53 19			0 331	8·106	
				1·40	1 41 37			0·331	8·106	
				1·45	1 31 31			0·331	8·105	
		H 11	A 8	1·15	1 54 59	1085·4		0·208	8·110	
				1·20	1 41 22			0·208	8·110	
				1·25	1 29 43			0·208	8·110	
				1·30	1 19 46			0·208	8·111	
		H 11	A 9	1·25	2 13 34	886·8		0·308	8·100	
				1·30	1 58 40			0·308	8·104	
				1·35	1 46 10			0·309	8·098	
				1·40	1 35 11			0·308	8·098	
22.		H 11	A 10	1·25	1 57 13	957·7		0·271	8·102	
				1·30	1 44 14			0·271	8·102	
				1·35	1 33 06			0·271	8·102	
				1·40	1 23 31			0·271	8·101	
		B.	D 5	1·05	3 29 05	1215·5	J.	0·287	8·136	
				1·10	3 01 51			0·287	8·135	
				1·15	2 39 07			0·287	8·136	
				1·20	2 23 35			0·287	8·134	
				1·25	2 04 02			0·287	8·134	
				1·30	1 50 19			0·287	8·136	
				1·35	1 38 33			0·287	8·132	
1848.					° ′ ″	seconds.				
Dec. 22.	Singapore.	B.	D 5	1·40	1 28 20	1515·5	J.	0·287	8·133	
		B.	A 7	1·10	3 27 52	868·7		0·331	8·103	
				1·15	3 02 08			0·331	8·103	
				1·20	2 40 18			0·331	8·108	
				1·25	2 22 04			0·331	8·106	
				1·30	2 06 17			0·331	8·110	
				1·35	1 52 49			0·331	8·111	
				1·40	1 41 10			0·330	8·114	
				1·45	1 31 08			0 330	8·113	
		B.	A 8	0·95	3 22 43	1085·4		0·308	8·121	
				1·00	2 54 02			0·208	8·121	
				1·05	2 30 22			0·208	8·124	
				1·10	2 11 01			0·208	8·111	
				1·15	1 54 45			0·208	8·120	
				1·20	1 41 10			0·208	8·115	
				1·25	1 29 31			0·208	8·118	
				1·30	1 19 34			0·208	8·121	
23.		B.	A 9	1·05	3 42 48	886·8		0·308	8·104	
				1·10	3 13 55			0·308	8·106	
				1·15	2 49 55			0·308	8·105	
				1·20	2 29 34			0·308	8·109	
				1·25	2 12 27			0·308	8·095	
				1·30	1 57 47			0·308	8·099	
				1·35	1 45 14			0·308	8·100	
				1·40	1 34 32			0·308	8 096	
		B.	A 10	1·05	3 16 08	957·7		0·271	8·089	
				1·10	2 50 38			0·271	8·094	
				1·15	2 29 25			0·271	8·096	
				1·20	2 11 42			0·271	8·095	
				1·25	1 56 28			0·271	8·099	
				1·30	1 43 49			0·271	8·092	
				1·35	1 32 42			0·271	8·095	
				1·40	1 23 10			0·271	8·095	
13.		H 12	D 5	1·05	3 28 55	1214·9	O.	0·287	8·136	
				1·10	3 01 41			0·287	8·138	
				1·15	2 38 55			0·287	8·142	
				1·20	2 19 53			0·287	8·142	
				1·25	2 03 47			0·287	8·142	
				1·30	1 50 02			0·287	8·143	
				1·35	1 38 11			0·287	8·147	
				1·40	1 28 04			0·287	8·146	
22.		H 12	A 7	1·10	3 28 03	867·1		0·332	8·111	
				1·15	3 02 04			0·331	8·117	
				1·20	2 40 05			0·331	8·126	
				1·25	2 21 40			0·331	8·129	
				1·30	2 05 59			0·331	8·132	
				1·35	1 52 40			0·331	8·129	
				1·40	1 40 59			0·331	8·133	
				1·45	1 30 55			0·331	8·134	
		H 12	A 8	0·95	3 22 30	1084·3		0·208	8·132	
				1·00	2 53 38			0·208	8·136	
				1·05	2 29 53			0·208	8·144	
				1·10	2 10 39			0·288	8·138	
				1·15	1 54 25			0·208	8·138	
				1·20	1 40 41			0·208	8·142	
				1·25	1 29 11			0·208	8·141	
				1·30	1 19 17			0·208	8·141	
20.		H 12	A 9	1·05	3 43 20	884·5		0·309	8·112	
				1·10	3 14 26			0·309	8·113	
				1·15	2 50 08			0·309	8·118	
				1·20	2 29 46			0·309	8·121	
				1·25	2 12 31			0·309	8·111	
				1·30	1 57 54			0·309	8·112	
				1·35	1 45 26			0·309	8·110	
				1·40	1 34 28			0·309	8·116	
		H 12	A 10	1·05	3 16 45	955·7		0·272	8·094	
				1·10	2 51 13			0·272	8·098	
				1·15	2 29 48			0·272	8·104	
				1·20	2 11 59			0·271	8·104	
				1·25	1 56 53			0·271	8·103	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1848.					° ′ ″	seconds.				
Dec. 20.	Singapore.	H 12	A 10	1·30	1 43 46	955·7	O.	0·271	8·112	
				1·35	1 32 49			0·271	8·115	
				1·40	1 23 05			0·271	8·117	8·114
1846.										
Jan. 20.	Pulo Peesang.	H 11	D 5	1·25	2 18 01	1156·25	I.	0·319	8·099	
				1·30	2 02 40			0·319	8·101	
				1·35	1 49 32			0·319	8·102	
				1·40	1 38 12			0·319	8·103	
		H 11	D 6	1·25	2 13 14	1170·6		0·307	8·087	
				1·30	1 58 21			0·307	8·091	
				1·35	1 45 38			0·307	8·094	
				1·40	1 34 52			0·307	8·089	
		H 11	A 6	1·20	2 15 48	945·5		0·279	8·106	
				1·40	1 25 52			0·279	8·096	
		H 11	A 7	1·30	2 16 44	839·0		0·355	8·088	
				1·40	1 49 35			0·356	8·088	
		H 11	A 8	1·15	2 09 31	1027·3		0·234	8·109	
				1·40	1 12 01			0·234	8·107	
		H 11	A 9	1·30	2 08 02	856·1		0·332	8·082	
				1·40	1 42 38			0·332	8·078	
		H 11	A 10	1·25	2 16 08	891·6		0·314	8·074	
				1·40	1 37 01			0·314	8·074	8·092
29.	Carimon ...	H 11	D 5	1·25	2 18 47	1158·2		0·319	8·061	
				1·30	2 03 06			0·319	8·071	
				1·35	1 49 50			0·319	8·075	
				1·40	1 38 31			0·319	8·075	
		H 11	D 6	1·25	2 13 22	1170·0		0·307	8·080	
				1·30	1 58 45			0·308	8·075	
				1·35	1 46 02			0·308	8·076	
		H 11	A 6	1·20	2 15 30	947·6		0·278	8·097	
				1·40	1 25 23			0·278	8·101	
		H 11	A 7	1·30	2 16 30	839·7		0·355	8·086	
				1·40	1 49 20			0·355	8·088	
		H 11	A 10	1·25	2 16 21	891·6		0·315	8·054	
				1·40	1 37 10			0·315	8·054	
		H 11	A 9	1·30	2 04 07	868·2		0·322	8·081	
				1·40	1 39 33			0·323	8·076	8·077
Feb. 22.	Lingin	H 11	A 9	1·30	2 04 54	868·5		0·322	8·066	
				1·40	1 40 07			0·322	8·063	
		H 11	D 5	1·25	2 18 28	1159·7		0·318	8·064	
				1·30	2 03 17			0·318	8·059	
				1·35	1 50 00			0·318	8·064	
				1·40	1 38 22			0·318	8·075	
		H 11	D 6	1·25	2 13 51	1171		0·307	8·060	
				1·30	1 58 56			0·307	8·063	
				1·35	1 46 02			0·307	8·070	
				1·40	1 35 14			0·307	8·064	
		H 11	A 6	1·20	2 15 41	949·2		0·278	8·072	
				1·40	1 25 37			0·278	8·070	
		H 11	A 7	1·30	2 16 56	840·8		0·355	8·060	
				1·40	1 49 43			0·355	8·060	
		H 11	A 10	1·25	2 16 58	891·7		0·315	8·037	
				1·40	1 37 32			0·315	8·040	8·062
June 24.	Sarāwak ...	H 11	D 6	1·25	2 09 52	1169·3		0·303	8·192	
				1·30	1 55 14			0·302	8·211	
				1·35	1 42 56			0·303	8·201	
				1·40	1 32 20			0·303	8·201	
		H 11	D 5	1·25	2 14 39	1157·6		0·315	8·193	
				1·30	1 59 45			0·315	8·192	
				1·35	1 46 50			0·314	8·197	
				1·40	1 35 54			0·315	8·193	
		H 11	A 6	1·40	1 23 05	949·7		0·273	8·196	
		H 11	A 7	1·30	2 13 45	838·2		0·352	8·190	
				1·40	1 47 10			0·352	8·190	
30.		H 11	A 8	1·15	2 07 04	1026·9		0·232	8·183	
				1·40	1 10 34			0·232	8·187	
July 3.		H 11	A 9	1·30	2 02 11	888·9		0·320	8·180	
		H 11		1·40	1 37 55			0·320	8·178	
		H 11	D 5	1·25	2 15 07	1158·6		0·315	8·180	
				1·30	1 59 56			0·314	8·187	
1846.					° ′ ″	seconds.				
July 3.	Sarāwak ...	H 11	D 5	1·35	1 47 08	1158·6	I.	0·314	8·186	
				1·40	1 36 02			0·314	8·189	
		H 11	D 6	1·25	2 09 45	1171·5		0·302	8·192	
				1·30	1 55 23			0·302	8·192	
				1·35	1 42 59			0·302	8·192	
				1·40	1 32 21			0·302	8·195	
		H 11	A 6	1·20	2 11 53	949·7		0·273	8·198	
				1·40	1 23 09			0·273	8·200	
		H 11	A 7	1·30	2 13 40	839·1		0·351	8·197	
		H 11	A 10	1·25	2 13 14	890·1		0·311	8·172	
				1·40	1 34 56			0·311	8·173	
		H 11	A 9	1·30	2 02 25	865·6		0·320	8·174	
				1·35	1 49 26			0·320	8·171	
				1·40	1 38 05			0·320	8·173	
				1·45	1 28 18			0·320	8·174	
		H 11	A 6	1·20	2 11 59	949·7		0·273	8·189	
				1·25	1 56 53			0·273	8·187	
				1·40	1 23 46			0·274	8·161	
				1·45	1 14 59			0·273	8·187	
		H 11	A 7	1·30	2 13 50	839·1		0·352	8·175	
				1·35	1 59 35			0·352	8·174	
				1·40	1 47 11			0·352	8·177	
				1·45	1 36 35			0·352	8·171	
		H 11	A 8	1·15	2 06 31	1028·0		0·231	8·193	
				1·40	1 10 19			0·231	8·193	
				1·45	1 03 27			0·232	8·184	8·186
Sept. 17.	Batavia ...	H 11	D 5	1·25	2 18 44	1182·2		0·313	7·896	
				1·30	2 03 18			0·313	7·898	
				1·35	1 50 08			0·313	7·898	
				1·40	1 39 28			0·314	7·870	
		H 11	D 6	1·25	2 13 09	1197·4		0·300	7·900	
				1·30	1 58 18			0·300	7·904	
				1·35	1 45 28			0·300	7·901	
				1·40	1 34 34			0·300	7·902	
		H 11	A 6	1·20	2 15 51	968·9		0·272	7·907	
				1·25	2 00 18			0·272	7·903	
				1·30	1 46 56			0·272	7·908	
				1·40	1 35 25			0·272	7·912	
		H 11	A 7	1·30	2 17 23	856·5		0·350	7·900	
				1·35	2 02 44			0·350	7·900	
				1·40	1 50 12			0·350	7·895	
				1·45	1 39 05			0·350	7·901	
		H 11	A 10	1·25	2 18 04	907·1		0·311	7·881	
				1·30	2 02 38			0·311	7·886	
				1·35	1 49 37			0·311	7·884	
				1·40	1 38 24			0·311	7·881	
		H 11	A 9	1·30	2 05 17	884·5		0·318	7·895	
				1·35	1 52 11			0·318	7·885	
				1·40	1 40 47			0·319	7·878	
				1·45	1 30 40			0·318	7·880	
		H 12	D 5	1·25	2 18 56	1182·2		0·312	7·922	
				1·30	2 03 26			0·312	7·924	
		H 11	D 5	1·35	1 50 17			0·312	7·922	
				1·40	1 38 54			0·312	7·922	
23.			D 6	1·25	2 13 26	1197·4		0·300	7·913	
				1·30	1 58 30			0·300	7·909	
				1·35	1 45 49			0·300	7·909	
				1·40	1 34 51			0·300	7·910	
Nov. 10.		H 11	D 5	1·25	2 18 08	1186·7		0·310	7·885	
				1·30	2 02 46			0·310	7·890	
				1·35	1 49 37			0·310	7·888	
				1·40	1 38 14			0·310	7·892	
		H 11	D 6	1·25	2 12 55	1200·9		0·298	7·887	
				1·30	1 58 10			0·298	7·889	
				1·35	1 45 30			0·298	7·889	
				1·40	1 34 29			0·298	7·895	
		H 11	A 7	1·30	2 16 53	859·6		0·347	7·878	
				1·35	2 02 24			0·347	7·875	
				1·40	1 49 48			0·347	7·874	
				1·45	1 38 55			0·347	7·871	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Disc. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
					° ′ ″	seconds.				
1846. Nov. 10.	Batavia ...	H 11	A 8	1·15	2 09 39	1049·5	1.	0·229	7·915	
				1·20	1 54 05			0·229	7·920	
				1·25	1 41 03			0·229	7·918	
				1·30	1 29 44			0·229	7·925	
		H 11	A 10	1·25	2 17 36	908·3		0·310	7·871	
				1·30	2 02 28			0·310	7·868	
				1·35	1 49 20			0·310	7·871	
				1·40	1 38 02			0 310	7·872	
		H 11	A 9	1·30	2 05 57	882·7		0·319	7·891	
				1·35	1 52 13			0·319	7·901	
				1·40	1 40 52			0·319	7·892	
				1·45	1 30 49			0·319	7·891	
1847. July 3.		H 11	D 5	1·25	2 12 43	1209·6		0·298	7·899	
				1·30	1 57 56			0·298	7·901	
				1·35	1 45 22			0·298	7·899	
				1·40	1 34 29			0 298	7·899	
		H 11	D 6	1·25	2 07 07	1223·7		0·286	7·920	
				1·30	1 53 12			0·286	7·914	
				1·35	1 41 08			0·286	7·912	
				1·40	1 30 46			0·286	7·908	
		H 11	A 7	1·30	2 13 46	867·6		0·339	7·900	
				1·35	1 59 34			0·340	7·898	
				1·40	1 47 14			0·340	7·898	
				1·45	1 36 35			0·340	7·896	
		H 11	A 8	1·15	2 06 13	1066·0		0·222	7·894	
				1·20	1 51 04			0·222	7·894	
				1·25	1 38 22			0·222	7·892	
				1·30	1 27 29			0·222	7·894	
		H 11	A 9	1·30	2 03 56	890·9		0·314	7·906	
				1·35	1 50 43			0·314	7·905	
				1·40	1 39 15			0·314	7·907	
				1·45	1 29 23			0·314	7·905	
4.		H 11	D 5	1·25	2 12 44	1209·6		0·298	7·899	
				1·30	1 57 56			0·298	7·901	
				1·35	1 45 19			0·298	7·901	
				1·40	1 34 26			0·298	7·901	
		H 11	D 6	1·25	2 07 33	1223·7		0·286	7·907	
				1·30	1 53 23			0·286	7·908	
				1·35	1 41 10			0·286	7·911	
				1·40	1 30 41			0·286	7·912	
		H 11	A 7	1·30	2 13 56	867·6		0·340	7·896	
				1·35	2 59 37			0·340	7·897	
				1·40	1 47 15			0·340	7·898	
				1·45	1 36 38			0·340	7·895	
		H 11	A 8	1·15	2 06 22	1066·0		0·223	7·885	
				1·20	1 51 13			0·222	7·889	
				1·25	1 38 30			0·222	7·887	
				1·30	1 27 31			0·222	7·893	
		H 11	A 9	1·30	2 04 06	890·9		0·314	7·901	
				1·35	1 50 50			0·314	7·902	
				1·40	1 39 26			0·314	7·901	
				1·45	1 29 32			0·314	7·899	
6.		H 11	D 5	1·25	2 12 33	1209·6		0·298	7·904	
				1·30	1 57 48			0·298	7·905	
				1·35	1 45 11			0·298	7·906	
				1·40	1 34 15			0·298	7·909	
		H 11	D 6	1·25	2 07 19	1223·7		0·286	7·914	
				1·30	1 53 13			0·286	7·913	
				1·35	1 41 02			0·286	7·916	
				1·40	1 30 34			0·286	7·917	
		H 11	A 7	1·30	2 13 37	867·6		0·339	7·904	
				1·35	1 59 26			0·339	7·903	
				1·40	1 47 06			0·339	7·903	
				1·45	1 36 26			0·339	7·903	
		H 11	A 8	1·15	2 06 05	1066·0		0·222	7·894	
				1·20	1 50 54			0·222	7·901	
				1·25	1 38 21			0·222	7·894	
				1·30	1 27 28			0·222	7·896	
		H 11	A 9	1·30	2 03 58	890·9		0·314	7·906	
					° ′ ″	seconds.				
1847. July 6.	Batavia ...	H 11	A 9	1·35	1 50 39	890·9	1.	0·314	7·908	
				1·40	1 39 20			0·314	7·904	
				1·45	1 29 26			0 314	7·903	
		H 11	D 5	1·25	2 12 41	1209·6		0·298	7·901	
				1·30	1 57 53			0·298	7·900	
				1·40	1 34 25			0·298	7·902	
		H 11	D 6	1·25	2 07 21	1223·7		0·286	7·913	
				1·30	1 52 13			0·286	7·914	
				1·35	1 41 06			0·286	7·914	
				1·40	1 30 42			0·286	7·911	
		H 11	A 7	1·30	2 13 50	867·6		0·340	7·899	
				1·35	1 59 38			0·340	7·897	
				1·40	1 47 18			0·340	7·897	
				1·45	1 36 33			0·340	7·899	
9.		H 11	A 8	1·15	2 06 15	1066·0		0·222	7·888	
				1·20	1 51 05			0·222	7·893	
				1·25	1 38 28			0·222	7·889	
				1·30	1 27 35			0·222	7·890	
		H 11	A 9	1·30	2 04 31	890·9		0·315	7·889	
				1·35	1 50 49			0·314	7·902	
				1·40	1 39 24			0·314	7·901	
				1·45	1 29 31			0·314	7·899	
10.		H 11	D 5	1·25	2 13 13	1209·6		0·298	7·886	
				1·30	1 58 26			0·298	7·886	
				1·35	1 45 41			0·298	7·889	
				1·40	1 34 50			0·298	7·886	
		H 11	D 6	1·25	2 07 50	1223·7		0·287	7·898	
				1·30	1 53 50			0·287	7·892	
				1·35	1 41 37			0·287	7·894	
				1·40	1 31 03			0·287	7·896	
		H 11	A 7	1·30	2 14 16	867·6		0·340	7·886	
				1·35	1 59 55			0·340	7·887	
				1·40	1 47 40			0·340	7·883	
				1·45	1 36 49			0·340	7·888	
		H 11	A 8	1·15	2 06 29	1066·0		0 222	7·881	
				1·20	1 51 53			0·222	7·883	
				1·25	1 38 40			0·222	7·886	
				1·30	1 27 34			0·222	7·891	
		H 11	A 9	1·25	2 20 00	890·9		0·315	7·889	
				1·30	2 04 25			0·315	7·891	
				1·35	1 51 04			0·314	7·893	
				1·40	1 39 39			0·315	7·891	
Aug. 3.		H 11	D 5	1·25	2 12 54	1209·6		0·298	7·893	
				1·30	1 58 11			0·298	7·893	
				1·35	1 45 26			0·298	7·897	
				1·40	1 34 32			0·298	7·897	
		H 11	D 6	1·25	2 07 27	1223·7		0·286	7·909	
				1·30	1 53 15			0·286	7·919	
				1·35	1 41 11			0·286	7·909	
				1·40	1 30 43			0·286	7·909	
		H 11	A 7	1·30	2 14 17	867·6		0·340	7·883	
				1·35	1 59 52			0·340	7·886	
				1·40	1 47 22			0·340	7·891	
				1·45	1 36 40			0·340	7·891	
		H 11	A 8	1·15	2 05 37	1066·0		0·222	7·907	
				1·20	1 53 38			0·222	7·908	
				1·25	1 37 56			0·221	7·913	
				1·30	1 27 10			0·222	7·907	
		H 11	A 9	1·25	2 19 29	890·9		0·314	7·901	
				1·30	2 03 59			0·314	7·903	
				1·35	1 50 41			0·314	7·906	
				1·40	1 39 18			0·314	7·904	
		H 11	A 10	1·25	2 02 08	963·7		0·275	7·877	
				1·30	1 48 34			0·275	7·879	
				1·35	1 36 58			0·275	7·880	
				1·40	1 26 55			0·275	7·883	
4.		H 11	D 5	1·25	2 12 48	1209·6		0·298	7·896	
				1·30	1 58 04			0·298	7·896	
				1·35	1 45 24			0·298	7·897	
				1·40	1 34 42			0·298	7·889	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1847.					° ′ ″	seconds.				
Aug. 4.	Batavia.	H 11	D 6	1·25	2 07 19	1223·7	I.	0·286	7·913	
				1·30	1 53 12			0·286	7·913	
				1·35	1 41 00			0·286	7·917	
				1·40	1 30 37			0·286	7·914	
		H 11	A 7	1·30	2 13 41	867·6		0·340	7·901	
				1·35	1 59 24			0·339	7·902	
				1·40	1 47 13			0·340	7·897	
				1·45	1 36 33			0·340	7·896	
		H 11	A 8	1·15	2 05 13	1066·0		0·221	7·915	
				1·20	1 50 32			0·221	7·913	
				1·25	1 37 48			0·221	7·920	
				1·30	1 26 59			0·221	7·916	
		H 11	A 9	1·25	2 19 28	890·9		0·314	7·902	
				1·30	2 03 52			0·314	7·907	
				1·35	1 50 39			0·314	7·907	
				1·40	1 39 10			0·314	7·909	
		H 11	A 10	1·25	2 01 56	463·7		0·275	7·883	
				1·30	1 48 30			0·275	7·881	
				1·35	1 36 38			0·274	7·893	
				1·40	1 26 57			0·275	7·881	
6.		H 11	D 5	1·25	2 13 00	1209·6		0·298	7·890	
				1·30	1 58 09			0·298	7·893	
				1·35	1 45 31			0·298	7·891	
				1·40	1 34 37			0·298	7·893	
		H 11	D 6	1·25	2 07 34	1223·7		0·287	7·905	
				1·30	1 53 22			0·286	7·907	
				1·35	1 41 19			0·287	7·904	
				1·40	1 30 45			0·286	7·908	
		H 11	A 7	1·30	2 14 05	867·6		0·340	7·889	
				1·35	1 59 40			0·340	7·894	
				1·40	1 47 19			0·340	7·894	
				1·45	1 36 38			0·340	7·894	
		H 11	A 8	1·15	2 05 44	1066·0		0·222	7·904	
				1·20	1 50 44			0·222	7·905	
				1·25	1 38 05			0·222	7·908	
				1·30	1 27 11			0·222	7·907	
		H 11	A 9	1·25	2 19 51	390·9		0·315	7·891	
				1·30	2 04 19			0·314	7·893	
				1·35	1 51 06			0·315	7·891	
				1·40	1 39 37			0·315	7·892	
		H 11	A 10	1·25	2 02 26	963·7		0·275	7·868	
				1·30	1 48 53			0·275	7·868	
				1·35	1 37 13			0·275	7·871	
				1·40	1 27 10			0 275	7·872	
7.		H 11	D 5	1·25	2 13 04	1209·6		0·298	7·889	
				1·35	1 58 08			0·298	7·894	
				1·40	1 45 32			0·298	7·893	
				1·45	1 34 43			0·298	7·889	
		H 11	D 6	1·25	2 07 47	1223·7		0·287	7·900	
				1·30	1 53 29			0·287	7·904	
				1·35	1 41 25			0·287	7·901	
				1·40	1 30 57			0·287	7·900	
		H 11	A 7	1·30	2 14 08	867·6		0·340	7·890	
				1·35	1 59 47			0·340	7·892	
				1·40	1 47 38			0·340	7·885	
				1·45	1 36 54			0·340	7·885	
		H 11	A 8	1·15	2 05 44	1066·0		0·222	7·905	
				1·20	1 50 40			0·222	7·909	
				1·25	1 38 06			0·222	7·909	
				1·30	1 27 07			0·222	7·912	
		H 11	A 9	1·25	2 19 53	890·9		0·315	7·892	
				1·30	2 04 27			0·315	7·891	
				1·35	1 51 08			0·315	7·890	
				1·40	1 39 37			0·314	7·893	
		H 11	A 10	1·25	2 02 08	963·7		0·275	7·878	
				1·30	1 48 28			0·275	7·884	
				1·35	1 37 02			0·275	7·878	
				1·40	1 26 58			0·275	7·881	
8.		H 11	D 5	1·25	2 12 46	1209·6		0·298	7·898	
				1·30	1 57 54			0·298	7·903	
1847.					° ′ ″	seconds.				
Aug. 8.	Batavia ...	H 11	D 5	1·35	1 45 26	1209·6	1.	0·298	7·897	
				1·40	1 34 41			0·298	7·898	
		H 11	D 6	1·25	2 07 37	1223·7		0·287	7·905	
				1·30	1 53 24			0·287	7·907	
				1·35	1 41 18			0·287	7·906	
				1·40	1 30 48			0·286	7·907	
		H 11	A 7	1·30	2 13 56	867·6		0·340	7·895	
				1·35	1 59 39			0·340	7·898	
				1·40	1 47 22			0·340	7·893	
				1·45	1 30 40			0·340	7·902	
		H 11	A 8	1·15	2 05 44	1066·0		0·222	7·904	
				1·20	1 50 42			0·222	7·907	
				1·25	1 37 58			0·221	7·913	
				1·30	1 27 03			0·221	7·914	
		H 11	A 9	1·30	2 03 56	890·9		0·314	7·905	
				1·35	1 50 43			0·314	7·904	
				1·40	1 39 24			0·314	7·900	
		H 11	A 10	1·25	2 02 06	963·7		0·275	7·892	
				1·30	1 48 41			0·275	7·887	
				1·35	1 36 57			0·275	7·892	
				1·40	1 27 07			0·275	7·884	7·897
17.	Lampongs, Sumatra.	H 11	D 5	1·25	2 12 09	1209·1		0·297	7·916	
				1·30	1 57 28			0·297	7·916	
				1·35	1 44 52			0·297	7·917	
				1·40	1 34 08			0·297	7·913	
		H 11	D 6	1·25	2 07 20	1221·7		0·287	7·922	
				1·30	1 53 10			0·287	7·924	
				1·35	1 41 07			0·287	7·921	
				1·40	1 30 41			0·287	7·920	
		H 11	A 7	1·30	2 13 22	867·6		0·339	7·909	
				1·35	1 59 11			0·339	7·908	
				1·40	1 46 50			0·339	7·910	
				1·45	1 36 16			0·339	7·907	
		H 11	A 8	1·15	2 04 36	1067·8		0·220	7·921	
				1·20	1 50 05			0·220	7·909	
				1·25	1 37 28			0·220	7·914	
				1·30	1 26 38			0·220	7·913	
		H 11	A 9	1·25	2 18 58	888·5		0·314	7·936	
				1·30	2 03 35			0·314	7·931	
				1·35	1 50 23			0·314	7·931	
				1·40	1 38 52			0·314	7·936	
		H 11	A 10	1·25	2 01 51	962·7		0·274	7·903	
				1·30	1 48 20			0·274	7·905	
				1·35	1 36 49			0·274	7·902	
				1·40	1 26 52			0·274	7·900	7·916
Sept. 22.	Pulo Bay, near Bencoolen.	H 11	D 5	1·25	2 12 02	1210		0·297	7·916	
				1·30	1 57 19			0·297	7·918	
				1·35	1 44 45			0·297	7·918	
				1·40	1 33 56			0·297	7·918	
		H 11	D 6	1·25	2 07 11	1222·9		0·286	7·923	
				1·30	1 52 59			0·286	7·926	
				1·35	1 40 57			0·286	7·924	
				1·40	1 30 31			0·286	7·924	
		H 11	A 7	1·30	2 13 21	868·7		0·339	7·903	
				1·35	1 58 51			0·338	7·918	
				1·40	1 46 43			0·338	7·908	
				1·45	1 36 03			0·338	7·909	
		H 11	A 8	1·15	2 04 34	1069·3		0·220	7·914	
				1·20	1 49 39			0·220	7·918	
				1·25	1 37 19			0·220	7·912	
				1·30	1 26 20			0·220	7·919	
		H 11	A 9	1·25	2 18 43	892·3		0·313	7·909	
				1·30	2 03 13			0·312	7·914	
				1·35	1 50 07			0·312	7·912	
				1·40	1 38 41			0 312	7·912	
		H 11	A 10	1·25	2 01 30	964·2		0·274	7·905	
				1·30	1 48 13			0·274	7·899	
				1·35	1 36 34			0·274	7·902	
				1·40	1 26 40			0·274	7·899	7·913
Oct. 16.	Padang ...	H 11	D 5	1·25	2 10 59	1207·5		0·296	7·960	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1847.					° ′ ″	seconds.				
Oct. 16.	Padang, Sumatra.	H 11	D 5	1·30	1 56 27	1207·5	I.	0·296	7·960	
				1·35	1 44 02			0·297	7·958	
				1·40	1 33 16			0·297	7·959	
		H 11	D 6	1·25	2 06 14	1223·5		0·285	7·946	
				1·30	1 52 14			0·285	7·946	
				1·35	1 40 14			0·285	7·945	
				1·40	1 29 52			0·285	7·945	
		H 11	A 7	1·30	2 12 39	864·8		0·339	7·955	
				1·35	1 58 39			0·339	7·950	
				1·40	1 46 11			0·339	7·959	
				1·45	1 35 46			0·339	7·952	
		H 11	A 8	1·15	2 03 24	1069·7		0·219	7 946	
				1·20	1 48 35			0·219	7·951	
				1·25	1 36 10			0·219	7·954	
				1·30	1 25 35			0·219	7·958	
		H 11	A 9	1·25	2 16 59	888·4		0·312	7·990	
				1·30	2 01 49			0·312	7·990	
				1·35	1 48 56			0·312	7·985	
				1·40	1 37 38			0·312	7·987	
		H 11	A 10	1·25	2 00 34	959·2		0·274	7·975	
				1·30	1 47 05			0·274	7·980	
				1·35	1 35 42			0·274	7·978	
				1·40	1 25 52			0·274	7·975	7·962
1848.										
Mar. 28.	Mount Ophir, near Malacca.	H 11	D 5	1·25	2 04 29	1194·3		0·292	8·273	
				1·30	1 50 37			0·292	8·275	
				1·35	1 38 48			0·292	8·274	
				1·40	1 28 31			0·292	8·278	
		H 11	A 7	1·25	2 06 54	856·7		0·334	8·217	
				1·30	1 53 23			0·334	8·217	
				1·35	1 41 35			0·334	8·221	
				1·40	1 31 31			0·334	8·218	
		H 11	A 8	1·15	1 57 23	1056·3		0·216	8·274	
				1·20	1 43 20			0·216	8·277	
				1·25	1 31 26			0·216	8·285	
				1·30	1 21 23			0·216	8·286	
		H 11	A 9	1·25	2 13 05	874·2		0·312	8·230	
				1·30	1 58 08			0·311	8·237	
				1·35	1 45 34			0·311	8·235	
				1·40	1 34 40			0·311	8·235	
		H 11	A 10	1·25	1 56 44	940·5		0·275	8·270	
				1·30	1 43 41			0·275	8·275	
				1·35	1 33 01			0·275	8·257	
				1·40	1 23 16			0·275	8·264	8 255
May 8.	Pulo Labooan.	H 11	D 5	1·25	2 04 28	1197·5		0·292	8·247	
				1·30	1 50 40			0·292	8·247	
				1·35	1 38 49			0·292	8·247	
				1·40	1 28 38			0·292	8·246	
		H 11	A 7	1·30	2 06 05	857·7		0·334	8·236	
				1·35	1 52 38			0·334	8·232	
				1·40	1 41 03			0·334	8·235	
				1·45	1 30 59			0·334	8·235	
		H 11	A 8	1·15	1 54 41	1071·3		0·211	8·246	
				1·20	1 41 00			0·211	8·248	
				1·25	1 29 28			0·211	8·251	
				1·30	1 19 26			0·211	8·254	
		H 11	A 9	1·25	2 11 52	878·3		0·310	8·232	
				1·30	1 57 14			0·310	8·234	
				1·35	1 44 42			0·310	8·234	
				1·40	1 33 56			0·310	8·232	
		H 11	A 10	1·25	1 55 49	947·7		0·272	8·242	
				1·30	1 42 56			0·272	8·244	
				1·35	1 32 10			0·272	8·234	
				1·40	1 22 46			0·273	8·228	8·240
29.	Sambooanga, Island of Mindanão.	H 11	D 5	1·25	2 05 56	1207·7		0·291	8·130	
				1·30	1 51 52			0·291	8·133	
				1·35	1 39 52			0·291	8·135	
				1·40	1 29 34			0·291	8·134	
		H 11	A 7	1·30	2 07 26	863·7		0·333	8·131	
				1·35	1 53 55			0·333	8·129	
1848.					° ′ ″	seconds.				
May 29.	Sambooanga, Island of Mindanão.	H 11	A 7	1·40	1 40 09	863·7	I.	0·333	8·129	
				1·45	1 31 59			0·333	8·129	
		H 11	A 8	1·15	1 55 54	1078·0		0·211	8·149	
				1·20	1 42 04			0·211	8·150	
				1·25	1 30 22			0·210	8·155	
				1·30	1 20 16			0·210	8·157	
		H 11	A 9	1·25	2 13 40	881·6		0·310	8·146	
				1·30	1 58 56			0·310	8·144	
				1·35	1 46 13			0·310	8·144	
				1·40	1 35 17			0·210	8·143	
		H 11	A 10	1·25	1 57 29	952		0·273	8·147	
				1·30	1 44 29			0·273	8·147	
				1·35	1 33 28			0·273	8·141	
				1·40	1 23 43			0·273	8·145	
30.		B.	D 5	1·25	2 04 34	1207·7	J.	0·289	8·167	
				1·30	1 50 27			0·289	8·177	
				1·35	1 38 58			0·290	8·166	
				1·40	1 28 41			0·289	8·168	
			A 7	1·30	2 06 45	863·7		0·332	8·157	
				1·35	1 52 57			0·331	8·166	
				1·40	1 41 40			0·332	8·153	
				1·45	1 31 34			0·322	8·153	
			A 8	0·95	3 23 38	1078·0		0·210	8·176	
				1·00	2 54 52			0·210	8·175	
				1·05	2 31 04			0·210	8·170	
				1·10	2 11 33			0·210	8·179	
				1·15	1 55 13			0·210	8·177	
				1·20	1 41 31			0·210	8·176	
				1·25	1 29 53			0·210	8·175	
				1·30	1 19 55			0·210	8·176	
			A 7	1·10	3 28 19	863·7		0·331	8·169	
				1·15	3 02 33			0·331	8·165	
				1·20	2 40 44			0·331	8·165	
				1·25	2 22 18			0·332	8·165	
			D 5	1·05	3 29 52	1207·7		0·289	8·167	
				1·10	3 02 30			0·289	8·170	
				1·15	2 39 47			0·289	8·170	
				1·20	2 20 37			0·289	8·174	
			A 9	1·05	3 41 45	881·60		0·309	8·174	
				1·10	3 13 05			0·309	8·175	
				1·15	2 49 04			0·309	8·177	
				1·20	2 28 48			0·309	8·181	
			A 9	1·25	2 11 43			0·309	8·181	
				1·30	1 57 06			0·309	8·185	
				1·35	1 44 44			0·309	8·181	
				1·40	1 34 07			0·309	8·174	
			A 10	1·05	3 14 34	952		0·272	8·174	
				1·10	2 49 24			0·272	8·176	
				1·15	2 28 25			0·272	8·176	
				1·20	2 10 43			0·272	8·178	
				1·25	1 55 52			0·272	8·173	
				1·30	1 42 45			0·271	8·187	
				1·35	1 32 02			0·272	8·177	
				1·40	1 22 37			0·272	8·175	8·162
June 21.	Keemah, Island of Celebes.	H 11	D 5	1·25	2 03 29	1199·5		0·290	8·263	
				1·30	1 49 43			0·290	8·266	
				1·35	1 38 01			0·290	8·264	
				1·40	1 27 50			0·290	8·266	
		B.	D 5	1·05	3 28 13			0·290	8·254	
				1·10	3 01 08			0·290	8·255	
				1·15	2 38 25			0·290	8·260	
				1·20	2 19 42			0·290	8 252	
				1·25	2 03 40			0·290	8·250	
				1·30	1 49 50			0·290	8·255	
				1·35	1 38 10			0·290	8·252	
				1·40	1 28 00			0·290	8·253	
		H 11	A 7	1·30	2 05 35	857·7	I.	0·333	8·249	
				1·35	1 52 08			0·333	8·252	
				1·40	1 40 42			0·333	8·246	
				1·45	1 30 35			0·333	8·250	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1848.					° ′ ″	seconds.				
June 21.	Keemah, Island of Celebes.	H 11	A 7	1·10	3 26 01	857·7	J.	0·333	8·257	
				1·15	3 00 27			0·332	8·258	
				1·20	2 38 27			0·332	8·270	
				1·25	2 20 42			0·333	8·258	
				1·30	2 05 07			0·332	8·258	
				1·35	1 51 38			0·332	8·259	
				1·40	1 40 28			0·332	8·245	
				1·45	1 30 22			0·332	8·250	
22.		H 11	A 8	0·95	3 20 34	1076·4		0·210	8·282	
				1·00	2 52 15			0·210	8·281	
				1·05	2 28 49			0·210	8·285	
				1·10	2 09 36			0·210	8·283	
				1·15	1 53 32			0·210	8·282	
				1·20	1 40 00			0·210	8·281	
				1·25	1 28 29			0·210	8·283	
				1·30	1 18 43			0·210	8·282	
		H 11	A 9	1·05	3 41 04	876·1		0·311	8·236	
				1·10	3 12 32			0·311	8·236	
				1·15	2 48 41			0·311	8·236	
				1·20	2 28 25			0·310	8·242	
				1·25	2 11 33			0·311	8·236	
				1·30	1 56 53			0·310	8·243	
				1·35	1 44 28			0·310	8·241	
				1·40	1 33 40			0·310	8·240	
		H 11	A 10	1·05	3 14 40	946·3		0·274	8·218	
				1·10	2 49 26			0·273	8·221	
				1·15	2 28 29			0·273	8·221	
				1·20	2 10 41			0·273	8·225	
				1·25	1 55 44			0·273	8·224	
				1·30	1 43 01			0·273	8·222	
				1·35	1 31 57			0·273	8·227	
				1·40	1 22 32			0·273	8·225	
		H 11	A 8	1·15	1 53 45	1071·4	1.	0·210	8·269	
				1·20	1 40 10			0·210	8·271	
				1·25	1 28 40			0·210	8·273	
				1·30	1 19 08			0·210	8·259	
		H 11	A 9	1·25	2 11 55	876·1		0·310	8·251	
				1·30	1 57 20			0·310	8·250	
				1·35	1 44 49			0·310	8·250	
				1·40	1 34 02			0·310	8·248	
		H 11	A 10	1·25	1 55 27	946·3		0·272	8·265	
				1·30	1 42 42			0·272	8·264	
				1·35	1 31 40			0·272	8·267	
				1·40	1 22 26			0·272	8·255	8·253
Aug. 29.	Cocos or Keeling Islands.	H 11	D 5	1·25	2 19 22	1279·1		0·289	7·293	
				1·30	2 03 48			0·289	7·296	
				1·35	1 50 34			0·289	7·295	
				1·40	1 39 16			0·289	7·291	
		H 11	A 7	1·30	2 21 55	914·0		0·332	7·276	
				1·35	2 06 45			0·332	7·277	
				1·40	1 53 43			0·332	7·276	
				1·45	1 42 25			0·332	7·275	
		H 11	A 8	1·15	2 09 16	1141·8		0·210	7·281	
				1·20	1 53 52			0·210	7·281	
				1·25	1 40 48			0·210	7·282	
				1·30	1 29 29			0·210	7·290	
		H 11	A 9	1·25	2 28 23	933·3		0·309	7·300	
				1·30	2 12 06			0·309	7·296	
				1·35	1 58 08			0·309	7·292	
				1·40	1 46 05			0·309	7·287	
		H 11	A 10	1·25	2 11 33	1007·5		0·273	7·272	
				1·30	1 56 59			0·273	7·272	
				1·35	1 44 24			0·272	7·275	
				1·40	1 33 37			0·272	7·275	
		B.	D 5	1·05	3 55 27	1279·1	J.	0·289	7·279	
				1·10	3 24 50			0·289	7·280	
				1·15	2 59 16			0·289	7·281	
				1·20	2 37 38			0·289	7·286	
				1·25	2 19 40			0·289	7·281	
				1·30	2 04 09			0·289	7·282	
1848.					° ′ ″	seconds.				
Aug. 29.	Cocos or Keeling Islands.	B.	D 5	1·35	1 50 53	1279·1	J.	0·289	7·284	
				1·40	1 39 23			0·289	7·284	
			A 7	1·10	3 54 13	914·0		0·332	7·265	
				1·15	3 25 14			0·332	7·265	
				1·20	3 00 41			0·332	7·265	
				1·25	2 39 47			0·332	7·270	
				1·30	2 22 08			0·332	7·274	
				1·35	2 07 00			0·332	7·274	
				1·40	1 53 57			0·332	7·272	
				1·45	1 42 33			0·332	7·274	
			A 8	0·95	3 47 34	1141·8		0·210	7·298	
				1·00	3 15 27			0·210	7·295	
				1·05	2 49 04			0·210	7·295	
				1·10	2 27 11			0·210	7·295	
				1·15	2 08 56			0·210	7·295	
				1·20	1 53 30			0·210	7·296	
				1·25	1 40 40			0·210	7·289	
				1·30	1 29 31			0·210	7·290	
21.			A 9	1·05	4 10 36	933·3		0·310	7·261	
				1·10	3 38 16			0·310	7·261	
				1·15	3 11 11			0·310	7·262	
				1·20	2 48 22			0·310	7·263	
				1·25	2 29 04			0·311	7·252	
				1·30	2 12 46			0·311	7·250	
				1·35	1 58 26			0·311	7·257	
				1·40	1 46 21			0·311	7·254	
			A 10	1·05	3 40 46	1007·5		0·273	7·251	
				1·10	3 12 14			0·273	7·252	
				1·15	2 48 22			0·273	7·254	
				1·20	2 28 16			0·273	7·256	
				1·25	2 11 23			0·273	7·253	
				1·30	1 56 41			0·273	7·260	
				1·35	1 44 21			0·273	7·256	
				1·40	1 33 38			0·273	7·256	
Sept. 12.		H 11	D 5	1·25	2 19 23	1279·1	1.	0·289	7·296	
				1·30	2 03 38			0·289	7·304	
				1·35	1 50 36			0·289	7·298	
				1·40	1 39 13			0·289	7·296	
		B.	D 5	1·05	3 55 27		J.	0·289	7·280	
				1·10	3 25 00			0·289	7·278	
				1·15	2 59 23			0·289	7·280	
				1·20	2 37 44			0·289	7·285	
				1·25	2 19 22			0·289	7·290	
				1·30	2 04 08			0·289	7·284	
				1·35	1 50 49			0·289	7·286	
				1·40	1 39 27			0·289	7·283	
			A 7	1·10	3 53 31	915·5		0·331	7·271	
				1·15	3 24 36			0·331	7·270	
				1·20	3 00 11			0·331	7·270	
				1·25	2 39 28			0·331	7·271	
				1·30	2 21 56			0·331	7·269	
				1·35	2 06 49			0·332	7·269	
				1·40	1 53 46			0·332	7·268	
				1·45	1 42 27			0·332	7·268	
13.		H 11	A 7	1·30	2 21 40	915·5	1.	0·331	7·278	
				1·35	2 06 33			0·331	7·279	
				1·40	1 53 32			0·331	7·278	
				1·45	1 42 16			0·331	7·276	
		H 11	A 8	1·15	2 08 56	1143·1		0·209	7·284	
				1·20	1 53 30			0·209	7·287	
				1·25	1 40 28			0·209	7·289	
				1·30	1 29 22			0·209	7·289	
14.		H 11	A 9	1·30	2 12 26	933·8		0·309	7·287	
				1·35	1 58 25			0·309	7·282	
				1·40	1 46 08			0·309	7·285	
				1·45	1 35 34			0·309	7·284	
		H 11	A 10	1·25	2 10 57	1009·5		0·271	7·276	
				1·30	1 56 25			0·271	7·278	
				1·35	1 44 01			0·271	7·277	
				1·40	1 33 19			0·271	7·275	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
848.					° ′ ″	seconds.				
pt. 14.	Cocos or Keeling Islands.	B.	A 8	0·95	3 47 59	1143·1	J.	0·209	7·282	
				1·00	3 15 45			0·209	7·278	
				1·05	2 49 18			0·209	7·281	
				1·10	2 27 24			0·209	7·281	
				1·15	2 09 02			0·209	7·282	
				1·20	1 53 36			0·209	7·284	
				1·25	1 40 40			0·209	7·280	
				1·30	1 29 34			0·279	7·279	
			A 9	1·05	4 10 24	933·8		0·310	7·263	
				1·10	3 38 11			0·310	7·262	
				1·15	3 11 05			0·310	7·263	
				1·20	2 48 17			0·310	7·264	
				1·25	2 29 05			0·310	7·251	
				1·30	1 12 35			0·310	7·253	
				1·35	1 58 22			0·310	7·258	
				1·40	1 46 15			0·310	7·257	
			A 10	1·05	3 40 29	1009·5		0·273	7·241	
				1·10	3 12 02			0·273	7·241	
				1·15	2 48 12			0·273	7·242	
				1·20	2 28 06			0·273	7·245	
				1·25	2 11 05			0·273	7·246	
				1·30	1 56 38			0·273	7·247	
				1·35	1 44 13			0·273	7·247	
				1·40	1 33 31			0·273	7·246	7·2745
849.										
n. 12.	Pulo Dinding.	H 11	D 5	1·25	2 04 34	1214·9	I.	0·288	8·125	
				1·30	1 50 39			0·288	8·129	
				1·35	1 38 49			0·288	8·128	
				1·40	1 28 32			0·287	8·131	
		H 11	A 7	1·30	2 06 53	867·8		0·330	8·103	
				1·35	1 53 20			0·330	8·104	
				1·40	1 41 33			0·330	8·104	
				1·45	1 31 30			0·330	8·104	
		H 11	A 8	1·15	1 55 25	1084·7		0·209	8·114	
				1·20	1 41 36			0·209	8·118	
				1·25	1 29 52			0·209	8·132	
				1·30	1 29 32			0·209	8·126	
		H 11	A 9	1·25	2 13 22	886·5		0·308	8·113	
				1·30	1 58 43			0·308	8·109	
				1·35	1 46 01			0·308	8·110	
				1·40	1 35 04			0·308	8·110	
		H 11	A 10	1·25	1 57 17	956·1		0·271	8·118	
				1·30	1 44 16			0·271	8·119	
				1·35	1 33 11			0·271	8·117	
				1·40	1 23 32			0·271	8·118	8·117
b. 9.	CarNicobar, Bay of Bengal.	H 11	D 5	1·25	2 03 29	1212·6		0·286	8·178	
				1·30	1 49 43			0·286	8·182	
				1·35	1 37 56			0·286	8·183	
				1·40	1 27 55			0·286	8·177	
		H 11	A 7	1·30	2 05 38	866·7		0·329	8·152	
				1·35	1 52 18			0·329	8·150	
				1·40	1 40 41			0·329	8·151	
				1·45	1 30 43			0·329	8·148	
		H 11	A 8	1·15	1 54 48	1083·6		0·209	8·135	
				1·20	1 41 19			0·209	8·134	
				1·25	1 29 37			0·209	8·139	
				1·30	1 18 32			0·208	8·148	
		H 11	A 9	1·25	2 12 52	885·8		0·308	8·131	
				1·30	1 58 04			0·308	8·132	
				1·35	1 45 29			0·308	8·131	
				1·40	1 34 39			0·308	8·129	
6.		B.	D 5	1·05	3 27 49	1212·6	J.	0·287	8·178	
				1·10	3 00 50			0·287	8·177	
				1·15	2 38 11			0·287	8·180	
				1·20	2 19 17			0·287	8·180	
				1·25	2 03 17			0·287	8·179	
				1·30	1 49 43			0·287	8·175	
				1·35	1 37 51			0·287	8·181	
				1·40	1 27 53			0·287	8·174	
			A 7	1·10	3 26 56	866·7		0·329	8·154	

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1849.					° ′ ″	seconds.				
Feb. 6.	CarNicobar, Bay of Bengal.	B.	A 7	1·15	3 01 19	866·7	J.	0·329	8·152	
				1·20	2 39 30			0·329	8·157	
				1·25	2 21 20			0·329	8·153	
				1·30	2 05 46			0·329	8·151	
				1·35	1 52 20			0·329	8·151	
				1·40	1 40 46			0·329	8·151	
				1·45	1 30 51			0·329	8·145	
		B.	A 8	0·95	3 21 30	1083·6		0·208	8·176	
				1·00	2 52 50			0·208	8·176	
				1·05	2 29 30			0·208	8·175	
				1·10	2 10 14			0·208	8·172	
				1·15	1 54 04			0·208	8·172	
				1·20	1 40 28			0·208	8·172	
				1·25	1 29 00			0·208	8·169	
				1·30	1 19 09			0·208	8·169	
		B.	A 9	1·05	3 41 28	885·8		0·307	8·139	
				1·10	3 12 46			0·307	8·141	
				1·15	2 48 46			0·307	8·149	
				1·20	2 28 47			0·307	8·141	
				1·25	2 11 41			0·307	8·146	
				1·30	1 57 10			0·307	8·144	
				1·35	1 44 28			0·307	8·156	
				1·40	1 34 01			0·307	8·143	
			A 10	1·05	3 15 19	955·1		0·271	8·147	
				1·10	2 50 11			0·271	8·143	
				1·15	2 29 06			0·271	8·142	
				1·20	2 11 13			0·271	8·146	
				1·25	1 56 12			0·271	8·144	
				1·30	1 43 22			0·271	8·144	
				1·35	1 32 25			0·271	8·141	
				1·40	1 22 48			0·271	8·145	
8.		H 11	A 10	1·25	1 56 34	955·1	I.	0·271	8·145	
				1·30	1 43 35			0·270	8·150	
				1·35	1 32 32			0·270	8·150	
				1·40	1 22 45			0·270	8·160	8·1555
Jan. 25.	Pulo Penang	H 11	D 5	1·25	2 03 19	1214·2		0·286	8·173	
				1·30	1 49 33			0·286	8·176	
				1·35	1 37 43			0·286	8·180	
				1·40	1 27 44			0·286	8·175	
		H 11	A 7	1·30	2 05 41	867·0		0·329	8·148	
				1·35	1 52 20			0·329	8·147	
				1·40	1 40 45			0·329	8·146	
				1·45	1 30 39			0·329	8·150	
		H 11	A 8	1·15	1 54 07	1083·9		0·208	8·163	
				1·20	1 40 33			0·208	8·162	
				1·25	1 29 00			0·208	8·164	
				1·30	1 19 07			0·208	8·167	
		H 11	A 9	1·25	2 12 08	885·6		0·307	8·154	
				1·30	1 57 26			0·307	8·155	
				1·35	1 44 51			0·307	8·157	
				1·40	1 34 04			0·307	8·155	
		H 11	A 10	1·25	1 56 32	954·7		0·271	8·151	
				1·30	1 43 37			0·271	8·152	
				1·35	1 32 31			0·271	8·153	
				1·40	1 22 58			0·271	8·153	8·159
Mar. 27.	Hastings' Island.	H 11	D 5	1·25	2 03 15	1212·3		0·287	8·191	
				1·30	1 49 32			0·287	8·191	
				1·35	1 37 44			0·286	8·195	
				1·40	1 27 42			0·287	8·192	
		H 11	A 7	1·30	2 05 09	866·1		0·329	8·177	
				1·35	1 51 43			0·329	8·180	
				1·40	1 40 18			0·329	8·176	
				1·45	1 30 16			0·329	8·177	
		H 11	A 8	1·15	1 53 53	1083·1		0·208	8·180	
				1·20	1 40 13			0·208	8·186	
				1·25	1 23 48			0·208	8·183	
				1·30	1 19 05			0·208	8·178	
		H 11	A 9	1·25	2 11 48	885		0·3069	8·169	
				1·30	1 57 16			0·3070	8·167	
				1·35	1 44 43			0·3069	8·168	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.				Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist.	Angles.					m.	X.	
				r, r′, r″, &c.	a, a′, a″, &c.							
1849.					°	′	″	seconds.				
Mar. 27.	Hastings' Island.	H 11	A 9	1·40	1	33	59	835	1.	0·3071	8·164	
		H 11	A 10	1·25	1	56	10	954·2		0·270	8·168	
				1·30	1	43	17			0·270	8·169	
				1·35	1	32	17			0·270	8·168	
				1·40	1	22	48			0·271	8·165	8·1772
April 16.	Moulmein.	H 11	D 5	1·25	2	03	19	1220·6		0·285	8·124	
				1·30	1	49	24			0·284	8·133	
				1·35	1	37	43			0·285	8·132	
				1·40	1	27	42			0·285	8·128	
		H 11	A 7	1·30	2	05	41	871·3		0·328	8·100	
				1·35	1	52	09			0·328	8·105	
				1·40	1	40	41			0·328	8·101	
				1·45	1	30	43			0·328	8·097	
		H 11	A 8	1·15	1	54	19	1087·6		0·208	8·130	
				1·20	1	40	43			0·208	8·130	
				1·25	1	29	04			0·208	8·135	
				1·30	1	19	13			0·208	8·135	
		H 11	A 9	1·25	2	11	53	888·2		0·306	8·135	
				1·30	1	57	14			0·306	8·137	
				1·35	1	44	43			0·306	8·137	
				1·40	1	33	43			0·306	8·145	
		H 11	A 10	1·25	1	56	29	959·5		0·269	8·107	
				1·30	1	43	35			0·269	8·108	
				1·35	1	32	26			0·270	8·111	
				1·40	1	23	02			0·270	8·104	
17.		B.	D 5	1·05	3	27	56	1220·6	J.	0·285	8·122	
				1·10	3	00	48			0·285	8·125	
				1·15	2	38	24			0·285	8·121	
				1·20	2	19	22			0·285	8·124	
				1·25	2	03	24			0·285	8·121	
				1·30	1	49	42			0·285	8·122	
				1·35	1	37	59			0·285	8·122	
				1·40	1	27	52			0·285	8·122	
			A 7	1·10	3	26	28	871·3		0·327	8·111	
				1·15	3	00	54			0·327	8·109	
				1·20	2	39	30			0·328	8·105	
				1·25	2	21	16			0·328	8·103	
				1·30	2	05	34			0·328	8·105	
				1·35	1	52	14			0·328	8·104	
				1·40	1	40	19			0·328	8·104	
18.			A 8	0·95	3	22	19	1087·6		0·208	8·134	
				1·00	2	53	24			0·207	8·141	
				1·05	2	30	17			0·208	8·132	
				1·10	2	10	46			0·208	8·133	
				1·15	1	54	38			0·208	8·130	
				1·20	1	40	55			0·208	8·131	
				1·25	1	29	19			0·208	8·132	
				1·30	1	19	31			0·208	8·128	
			A 9	1·05	3	41	42	888 2		0·307	8·110	
				1·10	3	12	51			0·307	8·110	
				1·15	2	48	45			0·307	8·120	
				1·20	2	28	46			0·307	8·117	
				1·25	2	11	44			0·307	8·121	
				1·30	1	57	13			0·307	8·120	
				1·35	1	45	00			0·307	8·111	
				1·40	1	33	56			0·307	8·123	
23.			A 10	1·05	3	15	28	959·5		0·270	8·106	
				1·10	2	50	07			0·270	8·108	
				1·15	2	29	03			0·270	8·107	
				1·20	2	11	17			0·270	8·107	
				1·25	1	56	14			0·270	8·106	
				1·30	1	43	26			0·270	8·108	
				1·35	1	32	23			0·270	8·105	
				1·40	1	22	52			0·270	8·105	8·1186
July 4.	Madras.	H 11	D 5	1·25	2	03	40	1228·1	I.	0·283	8·070	
				1·30	1	49	56			0·283	8·066	
				1·35	1	38	13			0·283	8·064	
				1·40	1	28	06			0·283	8·062	
		H 11	A 7	1·30	2	06	55	874·2		0·328	8·060	
				1·35	1	53	25			0·328	8·059	
1849.					°	′	″	seconds.				
July 4.	Madras.	H 11	A 7	1·40	1	41	45	874·2	1.	0·328	8·057	
				1·45	1	31	37			0 328	8·057	
		H 11	D 5	1·25	2	02	34	1229·8		0·281	8·090	
				1·30	1	48	53			0·281	8·092	
				1·35	1	37	09			0·281	8·095	
				1·40	1	27	10			0·281	8·093	
		H 11	A 7	1·30	2	05	20	878·1		0·325	8·076	
				1·35	1	52	00			0·325	8·073	
				1·40	1	40	26			0·325	8·073	
				1·45	1	30	24			0·325	8·074	
31.		H 11	A 8	1·15	1	53	19	1096·0		0·205	8·093	
				1·20	1	39	56			0·205	8·089	
				1·25	1	28	23			0·204	8·094	
				1·30	1	18	32			0·204	8·098	
		H 11	A 9	1·25	2	12	02	891·9		0·305	8·100	
				1·30	1	57	22			9·304	8·100	
				1·35	1	44	50			0·304	8·100	
				1·40	1	34	02			0·304	8·100	
		H 11	A 10	1·25	1	56	19	962·43		0·268	8·092	
				1·30	1	43	26			0·268	8·092	
				1·35	1	32	25			0·268	8·092	
				1·40	1	22	52			0·268	8·092	
Aug. 1.		B.	D 5	1·05	3	26	30	1229·8	J.	0·282	8·083	
				1·10	2	59	37			0·282	8·085	
				1·15	2	37	10			0·282	8·087	
				1·20	2	18	20			0·282	8·088	
				1·25	2	02	31			0·282	8·084	
				1·30	1	48	53			0·282	8·087	
				1·35	1	37	16			0·282	8·085	
				1·40	1	27	10			0·282	8·088	
2.			A 7	1·10	3	26	33	878·1		0·325	8·071	
				1·15	3	00	49			0·325	8·073	
				1·20	2	39	20			0·325	8·071	
				1·25	2	21	05			0·325	8·070	
				1·30	2	05	30			0·325	8·069	
				1·35	1	52	10			0·325	8·068	
				1·40	1	40	33			0·325	8·068	
				1·45	1	30	32			0·325	8·068	
4.			A 8	0·95	3	20	08	1096·0		0·204	8 096	
				1·00	2	51	26			0·204	8·105	
				1·05	2	28	23			0·204	8·101	
				1·10	2	09	13			0·204	8·094	
				1·15	1	53	14			0·204	8·097	
				1·20	1	39	43			0·204	8·098	
				1·25	1	28	19			0·204	8·096	
				1·30	1	18	35			0·204	8·094	
7.		B.	A 9	1·05	3	41	39	891 9		0·305	8·084	
				1·10	3	12	59			0·305	8·084	
				1·15	2	49	01			0·305	8·085	
				1·20	2	28	52			0·305	8·087	
				1·25	2	12	07			0·305	8·075	
				1·30	1	57	20			0·305	8·082	
				1·35	1	44	52			0·305	8·083	
				1·40	1	34	06			0·305	8·082	
		B.	A 10	1·05	3	15	29	962·43		0·268	8·081	
				1·10	2	50	08			0·268	8·082	
				1·15	2	29	05			0·268	8·081	
				1·20	2	10	55			0·268	8·093	
				1·25	1	56	20			0·269	8·077	
				1·30	1	43	30			0·269	8·076	
				1·35	1	32	26			0·269	8·077	
				1·40	1	23	00			0·269	8·073	
Sept. 27.			D 5	1·05	3	26	04	1231·5		0·281	8·085	
				1·10	2	59	12			0·281	8·087	
				1·15	2	36	46			0 281	8·089	
				1·25	2	02	13			0·281	8·086	
				1·30	1	48	40			0·281	8·086	
				1·35	1	37	02			0·281	8·087	
				1·40	1	27	01			0·281	8·087	
28.			A 7	1·10	3	26	03	878·1		0·325	8·075	

Table G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1849.					° ′ ″	seconds.				
Sept. 28.	Madras.	B.	A 7	1·15	3 00 31	878·1	J.	0·325	8·074	
				1·20	2 38 51			0·325	8·077	
				1·25	2 20 42			0·325	8·075	
				1·30	2 05 07			0·325	8·076	
				1·35	1 51 50			0·325	8·077	
				1·40	1 40 20			0·325	8·072	
				1·45	1 30 22			0·325	8·071	
			A 8	0·95	3 19 26	1099·1		0·204	8·084	
				1·00	2 51 12			0·204	8·082	
				1·05	2 28 03			0·204	8·084	
				1·10	2 08 55			0·204	8·083	
				1·15	1 52 55			0·204	8·082	
				1·20	1 39 34			0·204	8·078	
				1·25	1 28 08			0·204	8·077	
				1·30	1 18 23			0·204	8·077	
			A 9	1·05	3 41 43	895·2		0·304	8·053	
				1·10	3 13 07			0·304	8·053	
				1·15	2 49 07			0·304	8·054	
				1·20	2 29 04			0·304	8·052	
				1·25	2 12 02			0·304	8·050	
				1·30	1 57 18			0·304	8·054	
				1·35	1 44 52			0·304	8·054	
				1·40	1 34 03			0·304	8·053	
			A 10	1·05	3 15 32	963·6		0·268	8·069	
				1·10	2 50 10			0·268	8·071	
				1·15	2 29 04			0·268	8·070	
				1·20	2 11 20			0·268	8·069	
				1·25	1 56 18			0·268	8·068	
				1·30	1 43 29			0·268	8·066	
				1·35	1 32 36			0·269	8·060	
				1·40	1 22 52			0·268	8·069	
ct. 2.		H 11	D 5	1·25	2 02 10	1231·5	I.	0·281	8·089	
				1·30	1 48 34			0·281	8·090	
				1·35	1 37 05			0·281	8·085	
				1·40	1 26 52			0·281	8·093	
		H 11	A 7	1·30	2 05 01	878·1		0·325	8·077	
				1·35	1 51 39			0·325	8·079	
				1·40	1 40 05			0·325	8·079	
				1·45	1 30 16			0·325	8·074	
		H 11	A 8	1·15	1 53 32	1099·1		0·204	8·055	
				1·20	1 39 46			0·204	8·066	
				1·25	1 28 11			0·204	8·073	
				1·30	1 18 24			0·204	8·075	
		H 11	A 9	1·25	2 11 43	895·2		0·303	8·075	
				1·30	1 57 08			0·303	8·075	
				1·35	1 44 35			0·303	8·076	
				1·40	1 33 52			0·304	8·074	
		H 11	A 10	1·25	1 56 41	963·6		0·268	8·067	
				1·30	1 43 44			0·268	8·068	
				1·35	1 32 35			0·268	8·071	
				1·40	1 23 00			0·268	8·072	8·0784
1845.										
g. 14.	Singapore.	C 15	C 7	1·6	3 40 34	1343·41	P.	1·052	7·959	
				2·1	1 37 46			1·052	7·957	
16.				1·6	3 40 46	1343·0		1·052	7·955	
				2·1	1 37 49			1·051	7·961	
18.				1·6	3 40 44	1344·58		1·054	7·948	
				2·1	1 37 40			1·051	7·953	
19.				1·6	3 40 46	1344·91		1·051	7·947	
				2·1	1 37 37			1·050	7·954	
20.				1·6	3 41 31	1344·03		1·053	7·939	
				2·1	1 38 38			1·055	7·922	7·9495
1846.										
ar. 28.				1·6	3 36 24	1357·70		1·030	7·950	
				1·7	3 00 42			1·030	7·947	
				1·8	2 32 11			1·030	7·949	
				1·9	2 09 38			1·031	7·943	
				2·0	1 51 06			1·030	7·945	
				2·1	1 35 34			1·028	7·963	
				2·2	1 23 34			1·031	7·942	
				2·3	1 12 39			1·027	7·968	7·951

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1848.					° ′ ″	seconds.				
Nov. 28.	Singapore.	C 15	C7	1·6	3 25 57	1387·7	P.	0·978	7·969	
				1·7	2 51 34			0·977	7·975	
				1·8	2 24 25			0·977	7·980	
				1·9	2 03 31			0·978	7·969	
				1·6	3 24 29			0·977	7·996	
				1·7	2 50 24			0·977	8·000	
				1·8	2 33 14			0·977	8·001	
				1·9	2 02 15			0·977	7·997	
Dec. 26.				1·6	3 24 38	1387·2		0·978	7·997	
				1·7	2 50 40			0·978	7·998	
				1·8	2 23 34			0·977	8·006	
				1·9	2 01 59			0·977	8·010	7·991
1846.										
Jan. 21.	Pulo Pee-sang.			1·7	3 00 46	1352·4		1·034	7·962	
				1·8	2 32 00			1·033	7·971	
				2·2	1 23 42			1·035	7·952	
				2·3	1 12 56			1·033	7·970	7·964
30.	Carimon.			1·7	2 59 53	1357·2		1·028	7·961	
				1·8	2 31 16			1·028	7·964	
				2·2	1 23 02			1·028	7·964	
				2·3	1 12 58			1·030	7·948	7·959
Feb. 8.	Pulo Booāya			1·7	3 01 37	1361·3		1·031	7·911	
				1·8	2 33 06			1·031	7·910	
				2·2	1 24 25			1·034	7·887	
				2·3	1 13 18			1·030	7·918	7·907
21.	Lingin.			1·7	3 00 57	1358·8		1·029	7·938	
				1·8	2 32 18			1·028	7·943	
				2·2	1 23 46			1·030	7·930	
				2·3	1 13 09			1·029	7·938	7·937
May 21.	Sarāwak, Borneo.			1·7	2 57 10	1352·8		1·027	8·015	
				1·8	2 28 44			1·023	8·014	
				2·2	1 21 46			1·023	8·011	
				2·3	1 11 07			1·020	8·037	
July 3.				1·7	2 57 26	1356·4		1·026	8·000	
				1·8	2 29 10			1·024	8·013	
				2·2	1 22 00			1·025	8·010	
				2·3	1 12 01			1·026	7·997	
7.				1·7	2 56 40	1355·7		1·026	8·033	
				1·8	2 28 35			1·024	8·044	
				2·2	1 21 45			1·025	8·038	
				2·3	1 11 33			1·025	8·039	8·024
21.	Sambas, Borneo.			1·7	2 56 00	1356·6		1·022	8·017	
				1·8	2 27 48			1·019	8·034	
				2·3	1 10 54			1·020	8·044	8·032
25.	Permangkat at the mouth of the Sambas river.			1·7	2 55 18	1355·8		1·020	8·048	
				1·8	2 27 45			1·020	8·050	
				2·2	1 21 08			1·019	8·052	
				2·3	1 11 14			1·021	8·041	8·048
Aug. 4.	Pontiānak, Borneo.			1·7	2 56 33	1360·7		1·021	7·992	
				1·8	2 29 02			1·021	7·989	
				2·2	1 21 29			1·019	8·008	
				2·3	1 11 52			1·023	7·978	7·992
13.	Succadāna, Borneo.			1·7	2 57 50			1·022	7·948	
				1·8	2 29 24			1·020	7·962	
				2·2	1 22 14			1·021	7·956	
				2·3	1 12 12			1·022	7·945	7·953
Sept. 17.	Batavia, Island of Java.			1·7	3 00 46	1383·9		1·012	7·791	
				1·8	2 32 32			1·013	7·786	
				2·2	1 23 38			1·013	7·785	
				2·3	1 13 12			1·014	7·784	
				1·7	3 01 40			1·014	7·777	
				1·8	2 32 44			1·013	7·786	
				2·2	1 24 02			1·016	7·763	
				2·3	1 13 25			1·014	7·779	
				1·7	3 00 45	1383·6		1·011	7·785	
				1·8	2 31 58			1·009	7·795	
				2·2	1 23 50			1·013	7·769	
				2·3	1 12 57			1·010	7·792	
1847.										
July 19.				1·7	2 58 16	1395·3		0·995	7·787	

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1847.					° ′ ″	seconds.				
July 19.	Batavia, Island of Java.	C 15	C 7	1·8	2 30 15	1395·3	ρ.	0·995	7·787	
				2·2	1 22 34			0·996	7·777	
				2·3	1 12 09			0·995	7·783	
				1·7	2 58 04			0·994	7·791	
				1·8	2 29 48			0·993	7·797	
				2·2	1 22 22			0·995	7·785	
				2·3	1 12 17			0·996	7·774	
				1·7	2 59 26			0·997	7·767	
				1·8	2 30 14			0·994	7·791	
				2·2	1 22 47			0·997	7·770	
				2·3	1 12 08			0·995	7·787	
				1·7	2 58 50			0·995	7·786	
				1·8	2 30 39			0·995	7·788	
				2·2	1 22 41			0·995	7·783	
20.				1·7	2 58 43			0·995	7·785	
				1·8	2 30 55			0·995	7·786	
				2·2	1 23 00			0·998	7·764	
				2·3	1 12 16			0·995	7·785	
Aug. 5.				1·6	3 33 31			0·994	7·790	
				1·7	2 58 03			0·994	7·791	
				1·8	2 29 52			0·994	7·797	
				1·9	2 08 05			0·996	7·777	
				1·6	3 33 13			0·994	7·792	
				1·7	2 57 55			0·994	7·790	
				1·8	2 29 53			0·994	7·793	
				1·9	2 07 47			0·995	7·783	7·784
Sept. 29.	Ceram.			1·7	3 02 36	1389·2		1·002	7·725	
				1·8	2 33 59			1·012	7·723	
				2·2	1 24 26			1·012	7·721	
				2·3	1 13 59			1·013	7·716	7·721
Oct. 1.	Anjeer.			1·7	3 01 50	1387·3		1·012	7·757	
				1·8	2 33 08			1·020	7·759	
				2·2	1 24 02			1·012	7·753	
				2·3	1 13 28			1·012	7·757	7·757
3.	Cheringin.			1·7	3 01 16	1387·1		1·010	7·760	
				1·8	2 32 44			1·010	7·761	
				2·2	1 23 47			1·011	7·758	
				2·3	1 13 34			1·024	7·745	7·756
5.	Balembangan.			1·7	3 03 17	1386·1		1·013	7·729	
				1·8	2 34 18			1·012	7·733	
				2·2	1 24 55			1·014	7·717	
				2·3	1 14 10			1·013	7·725	7·726
6.	Chebiliang.			1·7	3 04 31	1397·3		1·014	7·615	
				1·8	2 35 28			1·012	7·634	
				2·2	1 25 33			1·014	7·619	
				2·3	1 14 43			1·013	7·627	7·623
10.	Chelangkahan.			1·7	3 03 33	1395·25		1·012	7·661	
				1·8	2 35 05			1·012	7·658	
				2·2	1 25 09			1·013	7·651	
				2·3	1 15 08			1·017	7·620	7·647
12.	Goonong Dādap.			1·7	3 00 50	1381·7		1·012	7·808	
				1·8	2 31 59			1·012	7·818	
				2·2	1 23 22			1·012	7·816	
				2·3	1 13 03			1·013	7·811	7·813
15.	Woorong Goonong.			1·7	3 01 09	1384·9		1·011	7·782	
				1·8	2 32 07			1·010	7·796	
				2·2	1 23 53			1·013	7·772	
				2·3	1 13 02			1·010	7·793	7·786
Dec. 1.	Chunjūr.			1·7	3 00 13	1392·5		1·003	7·754	
				1·8	2 31 46			1·002	7·757	
				2·2	1 23 25			1·004	7·746	
				2·3	1 12 37			1·001	7·767	7·756
4.	Kārang Tengga.			1·7	2 59 38	1387·4		1·004	7·801	
				1·8	2 31 02			1·003	7·810	
				2·2	1 23 04			1·004	7·797	
				2·3	1 12 31			1·003	7·807	7·804
7.	Chebrānok.			1·7	2 59 43	1390·0		1·004	7·784	
				1·8	2 30 52			1·002	7·799	
				2·2	1 23 11			1·005	7·776	
				2·3	1 12 40			1·004	7·783	7·786
1846.					° ′ ″	seconds.				
Dec. 8.	Palabūan Rātu.	C 15	C 7	1·7	2 59 55	1396·1	P.	1·000	7·744	
				1·8	2 31 37			1·000	7·744	
				2·2	1 23 05			1·000	7·745	
				2·3	1 12 44			1·000	7·744	7·744
10.	Chilotoe.			1·7	3 00 16	1390·6		1·004	7·765	
				1·8	2 31 38			1·003	7·772	
				2·2	1 23 27			1·005	7·757	
				2·3	1 12 34			1·002	7·764	7·764
12.	Pangangbahan.			1·7	2 59 31	1391·30		1·002	7·780	
				1·8	2 31 04			1·001	7·785	
				2·2	1 23 13			1·004	7·766	
				2·3	1 12 37			1·002	7·777	7·777
13.	Mooāro Chikasso.			1·7	3 02 24	1397·1		1·005	7·681	
				1·8	2 33 11			1·003	7·694	
				2·3	1 13 31			1·003	7·693	7·689
15.	Sidang Bārang.			1·7	3 01 23	1404·3		0·998	7·659	
				1·8	2 33 01			1·000	7·655	
				2·2	1 24 19			1·001	7·644	7·653
16.	Bejong Petair.			1·7	2 58 17	1391·8		1·000	7·802	
				1·8	2 30 17			1·000	7·801	
				2·2	1 22 38			1·001	7·789	
				2·3	1 12 25			1·002	7·783	7·794
21.	Bandong.			1·7	2 58 56	1387·3		1·002	7·812	
				1·8	2 30 42			1·001	7·814	
				2·2	1 22 32			1·002	7·808	
				2·3	1 12 31			1·003	7·802	7·809
24.	Garoet.			1·7	2 59 14	1389·5		1·002	7·790	
				1·8	2 30 46			1·001	7·798	
				2·2	1 22 50			1·002	7·788	
				2·3	1 12 23			1·001	7·794	7·793
29.	Permangpek			1·7	3 01 24	1400·6		1·000	7·689	
				1·8	2 32 32			0·999	7·698	
				2·2	1 23 33			0·999	7·700	
				2·3	1 13 08			0·999	7·700	7·697
1847.										
Jan. 1.	Cherūgnūktok.			1·7	2 59 17	1393·7		1·000	7·764	
				1·8	2 30 50			0·999	7·771	
				2·2	1 22 59			1·001	7·756	
				2·3	1 12 29			1·000	7·764	7·764
6.	Kālipoochen.			1·7	2 58 50	1394·0		0·998	7·769	
				1·8	2 30 21			0·997	7·787	
				2·2	1 22 40			0·998	7·775	
				2·3	1 12 18			0·998	7·777	7·777
10.	Chāwee.			1·7	2 58 24	1388·9		0·999	7·827	
				1·8	2 30 18			0·999	7·828	
				2·2	1 22 32			1·000	7·821	
				2·3	1 12 24			1·001	7·812	7·822
12.	Samadang.			1·7	2 58 16	1388·3		1·001	7·817	
				1·8	2 29 40			0·992	7·832	
				2·2	1 22 24			1·001	7·815	
				2·3	1 12 13			1·002	7·809	7·818
18.	Indramāyu.			1·7	2 58 40	1388·1		1·000	7·818	
				1·8	2 30 31			1·000	7·820	
				2·2	1 22 40			1·001	7·811	
				2·3	1 12 16			1·000	7·816	7·813
26.	Tegal.			1·7	2 27 54	1389·9		0·998	7·822	
				1·8	2 29 54			0·998	7·823	
				2·2	1 22 21			0·999	7·813	7·819
30.	Samārang.			1·7	2 58 15	1391·3		0·998	7·807	
				1·8	2 30 01			0·997	7·812	
				2·2	1 22 17			0·998	7·809	
				2·3	1 12 09			0·998	7·802	7·807
Feb. 2.	Japāra.			1·7	2 57 43	1387·9		0·999	7·833	
				1·8	2 29 55			0·998	7·842	
				2·2	1 22 05			0·999	7·833	
				2·3	1 12 02			1·001	7·823	7·833
5.	Ambarāwa.			1·7	2 56 38	1393·4		0·991	7·836	
				1·8	2 28 47			0·991	7·838	
				2·2	1 21 50			0·993	7·824	
				2·3	1 11 33			0·992	7·828	7·832

TABLE G.

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1847.						seconds.				
Feb. 13.	Solo.	C 15	C 7	1·7	2° 57′ 50″	1389·6	P.	0·998	7·824	
				1·8	2 29 55			0·999	7·823	
				2·2	1 22 03			0·998	7·829	
				2·3	1 11 46			0·998	7·831	7·827
18.	Nyāwee.			1·7	2 56 01	1383·42		0·998	7·909	
				1·8	2 27 59			0·997	7·917	
				2·2	1 21 31			1·000	7·898	
				2·3	1 11 19			0·998	7·909	7·908
22.	Soorabāya.			1·7	2 55 10	1381·91		0·995	7·946	
				1·8	2 27 18			0·994	7·942	
				2·2	1 20 55			0·995	7·933	
				2·3	1 10 55			0·996	7·948	7·942
Mar. 23.	Sumenap.			1·7	2 55 00	1382·3		0·996	7·934	
				1·8	2 27 14			0·996	7·940	
				2·2	1 20 52			0·997	7·932	
				2·3	1 11 02			0·998	7·918	
26.				1·7	2 55 32	1383·6		0·997	7·913	
				1·8	2 27 41			0·996	7·920	
				2·2	1 26 07			0·998	7·902	
				2·3	1 10 58			0·997	7·913	
31.				1·7	2 55 49	1382·9		0·998	7·910	
				1·8	2 28 04			0·998	7·912	
				2·2	1 21 28			1·000	7·897	
				2·3	1 11 18			1·000	7·896	7·916
pril 8.	Pulo Kuneeang.			1·7	2 54 37	1382·6		0·996	7·902	
				1·8	2 26 52			0·995	7·946	
				2·2	1 20 39			0·996	7·938	
				2·3	1 10 53			0·998	7·922	
				1·7	2 55 43	1381·3		0·998	7·921	
				1·8	2 27 58			0·998	7·924	
				2·2	1 21 26			1·000	7·908	
				2·3	1 11 22			1·000	7·903	
10.				1·7	2 55 22	1374·75		1·001	7·957	
				1·8	2 27 28			1·000	7·965	
				2·2	1 21 05			1·001	7·953	
				2·3	1 11 08			1·002	7·942	7·932
26.	Bezooki.			1·7	2 56 19	1386·75		0·997	7·880	
				1·8	2 28 39			0·997	7·878	
				2·2	1 21 42			0·998	7·867	
				2·3	1 11 03			0·995	7·892	7·879
y 12.	Kedeeri.			1·7	2 58 14	1395·8		0·995	7·784	
				1·8	2 30 16			0·995	7·782	
				2·2	1 22 31			0·997	7·770	
				2·3	1 12 18			0·997	7·771	
13.				1·7	2 59 02			0·997	7·767	
				1·8	2 30 20			0·995	7·781	
				2·2	1 22 46			0·998	7·763	
				2·3	1 12 07			0·995	7·781	7·775
21.	Patchitan.			1·7	2 58 36	1399·6		0·994	7·756	
				1·8	2 30 07			0·993	7·766	
				2·2	1 22 34			0·995	7·753	
				2·3	1 12 15			0·995	7·754	7·757
e 1.	Manāroo.			1·7	2 56 41	1392·0		0·995	7·831	
				1·8	2 28 38			0·994	7·838	
				2·2	1 21 49			0·996	7·821	
				2·3	1 11 30			0·995	7·827	7·829
6.	Kārang Bolang.			1·7	2 58 02	1396·5		0·997	7·804	
				1·8	2 29 36			0·996	7·815	
				2·2	1 22 25			0·998	7·795	
				2·3	1 11 56			0·997	7·806	7·805
9.	Chilāchap.			1·7	2 58 32	1394·9		0·996	7·791	
				1·8	2 30 07			0·996	7·790	
				2·2	1 22 32			0·997	7·778	
				2·3	1 12 11			0·997	7·781	7·785
25.	Kandang Aur.			1·7	2 57 01	1395·3		0·993	7·814	
				1·8	2 28 49			0·992	7·823	
				2·2	1 22 10			0·993	7·794	
				2·3	1 11 22			0·991	7·824	7·814
19.	Lampongs, Sumātra.			1·6	3 32 14	1395·5		0·992	7·808	

Date.	Station.	Magnets employed.		Exp. of deflec.		Observed time of 300 vibrations.	Declinometer.	Results.		General mean.
		Suspended.	Deflecting.	Dist. r, r′, r″, &c.	Angles. a, a′, a″, &c.			m.	X.	
1847.						seconds.				
Aug. 19.	Lampongs, Sumātra.	C 15	C 7	1·7	2° 57′ 09″	1395·5	P.	0·992	7·805	
				1·8	2 29 06			0·991	7·811	
				1·9	2 07 10			0·993	7·801	7·809
Sept. 1.	Poolo Bay, near Bencoolen.			1·6	3 32 29	1396·6		0·991	7·800	
				1·7	2 57 24			0·991	7·796	
				1·8	2 29 18			0·991	7·802	
				1·9	2 07 42			0·993	7·780	7·794
Oct. 22.	Padang.			1·6	3 29 24	1392·9		0·987	7·867	
				1·7	2 54 50			0·987	7·863	
				1·8	2 27 17			0·987	7·865	
				1·9	2 05 30			0·988	7·857	7·863
1848.										
May 6.	Pulo Labooan.			1·6	3 23 50	1376·6		0·985	8·087	
				1·7	2 49 27			0·983	8·101	
				1·8	2 22 58			0·984	8·097	
				1·9	2 01 55			0·985	8·086	8·093
27.	Samboo-anga.			1·6	3 24 22	1386·0		0·980	8·010	
				1·7	2 50 26			0·989	8·011	
				1·8	2 23 33			0·986	8·014	
				1·9	2 02 18			0·981	8·007	8·011
June 21.	Keemah.			1·6	3 21 50	1375·7		0·982	8·121	
				1·7	2 48 16			0·981	8·123	
				1·8	2 21 33			0·980	8·131	
				1·9	2 00 42			0·982	8·120	8·124
Sept. 1.	Cocos or Keeling Islands.			1·6	3 48 51	1462·1		0·982	7·171	
				1·7	3 10 21			0·980	7·182	
				1·8	2 40 37			0·981	7·178	
				1·9	2 16 39			0·981	7·177	
7.				1·6	3 48 06	1465·4		0·979	7·170	
				1·7	3 09 58			0·978	7·176	
				1·8	2 40 07			0·978	7·176	
				1·9	2 16 15			0·978	7·174	
12.				1·6	3 48 31	1465·6		0·980	7·157	
				1·7	3 10 42			0·980	7·156	
				1·8	2 40 57			0·981	7·151	
				1·9	2 16 51			0·981	7·152	7·167
1849.										
Jan. 3.	Malacca.			1·6	3 24 12	1390·68		0·976	7·986	
				1·7	2 50 22			0·976	7·986	
				1·8	2 23 05			0·975	7·999	
				1·9	2 02 01			0·976	7·989	7·981
13.	Pulo Dinding.			1·6	3 24 07	1387·2		0·978	8·012	
				1·7	2 50 05			0·978	8·016	
				1·8	2 23 12			0·977	8·020	
				1·9	2 01 56			0·978	8·011	8·015
27.	Penang.			1·6	3 22 42	1390·0		0·974	8·022	
				1·7	2 49 04			0·973	8·023	
				1·8	2 22 20			0·973	8·027	
				1·9	2 01 17			0·974	8·020	8·024
Feb. 10.	Nicobar.			1·6	3 23 29	1390·2		0·974	8·000	
				1·7	2 49 23			0·973	8·008	
				1·8	2 22 54			0·974	8·004	
				1·9	2 01 49			0·975	7·995	8·002
Mar. 27.	Hastings' Island.			1·6	3 21 35	1386·9		0·973	8·061	
				1·7	2 47 28			0·971	8·077	
				1·8	2 21 18			0·971	8·073	
				1·9	2 00 29			0·972	8·062	8·068
April 16.	Moulmein.			1·6	3 24 51	1391·4		0·976	7·973	
				1·7	2 50 28			0·975	7·983	
				1·8	2 23 40			0·975	7·983	
				1·9	2 02 31			0·976	7·972	7·978
Aug. 25.	Madras.			1·6	3 23 42	1400·3		0·967	7·943	
				1·7	2 49 32			0·966	7·952	
				1·8	2 22 20			0·965	7·968	
				1·9	2 01 21			0·965	7·963	
Oct. 3.				1·6	3 23 02	1402·1		0·965	7·943	
				1·7	2 49 15			0·965	7·946	
				1·8	2 22 30			0·965	7·950	
				1·9	2 01 12			0·965	7·950	7·951

Absolute Determinations of Dip, Horizontal and Total Intensity, and Variation at different Stations in the Archipelago, together with the Heights, in Feet, of some of the Stations in Sumātra determined by Cary's Portable Barometer.

Table H.

Date.	Station.	Latitude.	Longitude.	Dip corrected to Jan. 1, 1848.	Horizontal Intensity.	Total Intensity.	Variation.	Altitude above sea level.
1845	Singapore	1° 18′ 32″ N.	103° 56′ 30″ E.	° ′	8·0947	8·306	1° 36′ 46″·6 E.	S. L.*
1846	Singapore	....	....	12 51·8 S.	8·121	8·333	....	S. L.
1847	Singapore	....	....	12 56·2	8·116	8·328	....	S. L.
1848	Singapore	....	....	12 56·7	8·114	8·326	1 36 15	S. L.
January, 1846	Pulo Peesang	1 27 52·6	103 19 15	......	8·092	......	1 31 07	S. L.
	Carimons	0 59 22	103 27 00	......	8·077	......	1 23 05	S. L.
February.	Pulo Booāya	0 09 09	104 21 00	......	......	......	1 28 49	S. L.
	Lingin	0 11 39 S.	104 37 00	......	8·062	......	1 19 07	S. L.
May, June and July.	Sarāwak	1 33 54 N.	110 29 00	11 14·9	8·186	8·346	1 09 40	U.†
July.	Sambas	1 22 00	109 28 00	11 31·0	8·166	8·334	1 15 50	U.
July.	Permanket	1 10 29	109 04 15	12 35·8	8·182	8·384	1 09 33	S. L.
August.	Pantiānak	0 01 19·3 S.	109 30 00	12 45·0	8·125	8·331	1 31 19	S. L.
August.	Succadāna	1 15 33	109 57 00	17 02·1	8·086	8·457	1 22 39	S. L.
September.	Batavia	6 09 52	106 58 00	27 05·4	7·897	8·870	0 47 07	S. L.
September 29.	Ceram	6 07 05	106 15 00	27 14·2	7·850	8·829	0 34 25	S. L.
October 1.	Anjeer	6 02 47	106 01 00	26 32·0	7·887	8·815	0 58 11	S. L.
October 3.	Cheringin	6 22 05	105 46 45	27 34·0	7·886	8·895	0 50 44	S. L.
October 5.	Palambangan	6 31 00	105 54 45	28 08·6	7·855	8·909	0 59 10	U.
October 7.	Chebiliang	6 47 00	105 49 15	28 41·1	7·753	8·834	0 20 36	U.
October 10.	Chelangkahan	6 54 00 ?	106 06 45 ?	28 23·9	7·647	8·838	0 13 46	U.
October 12.	Goonong Dādap	6 28 00 ?	106 06 00 ?	27 31·7	7·943	8·958	0 52 57	U.
October 15.	Woorong Goonong	6 11 00 ?	106 10 00 ?	27 23·2	7·916	8·915	0 40 04	U.
November 23.	Tegu	6 43 04	106 58 45 ?	28 45·4	......	......	0 11 32 ?	U.‡
November 27.	Pangerango	6 51 00 ?	106 59 00 ?	29 45·7	......	......	....	U.§
December 1.	Chunjūr	6 50 08	107 09 45	28 26·1	7·886	8·967	1 35 28 ?	U.‖
December 4.	Kārang Tengga	6 58 16	106 47 45	28 24·1	7·934	9·020	1 13 18	U.
December 7.	Chebrānok	6 57 14	106 25 30	28 30·8	7·916	9·009	0 35 09	S. L.
December 8.	Wyn Cooper's Bay	7 05 00 ?	106 36 30	29 21·5	7·873	9·033	0 32 20	S. L.
December 10.	Chilotoe	7 11 17	106 27 00	28 54·3	7·894	9·017	0 27 38	U.
December 11.	Pangangbahan	7 30 37	106 19 00	29 44·4	7·907	9·106	0 10 05	U.
December 13.	Mooāro Chikasso	7 28 00	106 38 00	30 08·3	7·817	9·039	0 13 14	S. L.
December 15.	Sidang Bārang	7 30 00 ?	107 10 00	30 15·0	7·781	9·007	0 05 13	U.
December 16.	Bejong Petair	7 13 36	107 02 00	29 36·5	7·924	9·113	0 16 23	U.
December 21.	Bandong	6 55 44	107 40 30	28 34·4	7·939	9·040	0 26 23	U.
December 24.	Garoet	7 13 54	107 55 00	29 01·5	7·925	9·060	0 25 21	U.
December 29.	Permangpek	7 39 23	107 45 15	30 14·8	7·826	9·059	0 20 20	U.
Jan. 1, 1847	Cherūgnūktok	7 38 25	108 09 45	30 10·9	7·894	9·132	0 18 13	U.
Jan. 6.	Kālipoochen	7 39 02	108 52 30	29 53·9	7·907	9·121	0 57 46	S. L.¶
Jan. 8.	Banjcer	7 23 08	108 42 00	29 09·9	......	......	0 27 59	U.
Jan. 10.	Chāwee	7 09 34	108 23 00	28 41·9	7·953	9·066	0 33 23	U.
Jan. 12.	Samadang	6 51 14	108 04 45	28 00·2	7·948	9·002	0 30 24	U.
Jan. 14.	Cheribon	6 43 34	108 42 00	27 52·0	......	......	0 31 41	S. L.
Jan. 18.	Indramāyu	6 19 35	108 25 45	27 30·9	7·944	8·957	0 41 05	S. L.
Jan. 26.	Tegal	6 51 57	109 15 30	28 05·1	7·950	9·010	0 37 59	S. L.
Jan. 30.	Samārang	6 59 42	110 30 45	27 04·6	7·937	8·915	0 23 51	S. L.
Feb. 2.	Japara	6 36 07	110 38 15	27 29·9	7·964	8·978	0 24 55	S. L.
Feb. 5.	Ambarāwa	7 16 08	110 28 45	29 27·7	7·963	9·146	0 33 17	U.
Feb. 10.	Balembang	7 24 00 ?	110 37 00	29 02·4	......	......	....	U.
Feb. 13.	Solo	7 35 00 ?	110 53 30	29 12·7	7·958	9·118	0 35 59	U.
Feb. 15.	Nyāwee	7 23 52	111 29 15	28 59·9	8·040	9·193	0 29 25	U.
Feb. 22.	Bankāwa, Solo river	7 00 26	112 21 00	27 47·3	8·025	9·072	0 28 38	U.
Feb. 25.	Soorabāya	7 16 01	112 44 30	28 53·0	8·075	9·222	0 51 55	S. L.
March.	Sūmenap	7 00 26	113 51 15	27 45·8	8·048	9·096	0 44 15	S. L.
April.	Pulo Kuneeang	6 51 32	115 16 30	27 25·6	8·064	9·086	0 32 07	S. L.
Apr. 26.	Bezooki	7 43 29	113 42 45	27 07·5	8·011	9·000	0 29 59	S. L.
May.	Kedeeri	7 48 29	112 00 00	29 52·2	7·905	9·115	0 28 28	U.
May 21.	Patchitan	8 12 56	111 05 30	30 36·0	7·887	9·163	0 19 32	S. L.
June 1.	Munoori	7 35 22	110 04 00	29 20·5	7·960	9·130	0 18 18	U.
June 6.	Kārang Bolong	7 45 44	109 27 00	29 55·9	7·935	9·157	0 32 13	S. L.
June 9.	Chilāchap	7 44 29	108 57 15	29 45·8	7·915	9·118	0 36 57	S. L.
June 12.	Aji Bārang	2 24 49	109 03 30	27 22·1	......	......	0 54 38	U.
June 25.	Kandang Aur	6 23 46	108 04 30	......	7·944	......	0 18 13	S. L.
August.	Lampongs	5 26 12	105 20 15	26 15·7	7·916	8·827	1 12 30	S. L.
September.	Bencoolen	3 53 54	102 28 45	23 54·0	7·913	8·655	1 05 09	S. L.

* S.L. Sea level. † U.; height unknown. ‡ November 22nd, variation = 10′ 20″ E. and 23rd = 12′ 45″.

§ Pangerango, about 10,000 feet high. ‖ By morning sights 1° 33′ 30″. Afternoon 1° 31′ 17″, and by equal altitudes 1° 35′ 28″.

¶ This variation is different from the others, but by equal altitudes = 0° 57′ 26″ E.

TABLE H.

Date.	Station.	Latitude.	Longitude.	Dip corrected to Jan. 1, 1848.	Horizontal Intensity.	Total Intensity.	Variation.	Altitude above sea level.
October, 1847	Padang	0° 58′ 58″ S.	100° 31′ 15″ E.	18° 32′·2 S.	7·962	8·397	1° 24′ 26″ E.	S. L.
Nov. 1 and 2.	Solok	0 47 05	100 55 45	17 50·8	......	......	1 39 05	1232
Nov. 5.	Sijonjong	0 41 47	101 19 30	17 49·8	......	......	1 21 38	458
Nov. 8.	Bua Pānjāng	0 28 09	101 08 00	17 11·4	......	......	1 22 29	U.
Nov. 10.	Pāyacombo	0 13 16	101 04 45	16 38·2	......	......	1 29 46	1631
Nov. 11.	Fort Vande Capellen	0 27 34	101 03 00	17 12·3	......	......	1 28 13	U.
Nov. 14.	Padang Panjang	0 22 00 ?	100 42 30	17 47 5	......	......	1 33 30	2559
Nov. 16.	Fort de Kock	0 13 00 ?	100 27 15	16 59·6	......	......	1 09 23	3043
Nov. 17.	Menindjo	0 13 00	100 14 00	17 00·8	......	......	1 31 48	1492
Nov. 18.	Balembangan	0 11 44	100 10 15	16 47·3	......	......	1 36 39	2583
Nov. 19.	Peesang	0 07 55	100 12 00	16 33·4	......	......	1 46 33	U.
Nov. 20.	Bonjol	0 00 52	100 13 30	16 38·5	......	......	1 35 30	650
Nov. 21.	Loobisikapping	0 06 55 ? N.	......	16 08·3	......	......	....	1475
Nov. 22.	Batoo Bedindi	0 16 00 ?	......	15 49·2	......	......	1 35 45	909
Nov. 23.	Lender	0 24 24	100 04 00	15 35·2	......	......	....	695
Nov. 24 and 25.	Rau	0 33 07	99 56 45	15 37·4	......	......	1 37 27	848
Nov. 26.	Pionghay	0 36 19	99 52 15	15 50·2	......	......	1 38 49	1756
Nov. 27.	Batong	0 39 00	99 47 15	15 41·5	......	......	....	1941
Nov. 28.	Kotanopan	0 42 00	99 42 45	15 19·9	......	......	1 34 30	1420
Nov. 29.	Tāna Bātoo	0 44 26	99 30 45	15 03·1	......	......	....	1707
Dec. 1.	Fort Elout	0 50 56	99 32 20	14 48·1	......	......	1 43 35	680
Dec. 3.	Singalāngan	1 14 48	......	14 11·9	......	......	....	U.
Dec. 6.	Padang Sidompang	1 22 33	99 22 45	13 47·0	......	......	....	928
Dec. 12 to 16.	Sibogha	1 44 42	98 56 15	13 02·5	......	......	1 40 38	S. L.
Dec. 19 and 20.	Bāros	2 00 51	98 31 30	12 58·0	......	......	1 16 42	S. L
Dec. 23 to 25.	Sinkel	2 16 37	97 51 35	12 23·5	......	......	1 34 08	S. L.
Dec. 31.	Goonong Satoolie, Pulonias .	1 17 35	97 40 50	14 05·8	......	......	1 43 38	S. L.
Jan. 10 to 13, 1848.	Nātal	0 33 44	99 20 15	15 32·4	......	......	1 28 08	S. L.
March 28.	Mount Ophir, near Malācca .	2 22 00 ?	102 38 00 ?	9 55·1	8·255	8·380	....	U*.
May 3 to 5.	Pulo Labooan	5 16 59·5	115 18 15	2 51·6	8·240	8·250	1 36 27	S. L.
May 25 and 26.	Sambooanga	6 54 20	122 13 45	1 18·2 N.	8·162	8·164	1 15 24	S. L.
June 21.	Keemah	1 21 55	125 07 59	11 01·4 S.	8·253	8·408	1 39 47	S. L.
June 27.	Tondāno	1 17 31	124 50 11	10 54·3	......	......	1 07 37	2240
June 29.	Manādo	1 29 11	124 51 11	10 43·6	......	......	1 26 16	S. L.
Aug. and Sept.	Cocos	12 05 38 S.	96 50 30	39 18·5	7·2745	9·400	1 10 42 W.	S. L.
January 2, 1849 ...	Malacca	2 11 19 N.	102 17 00	11 25·2	8·114	8·278	1 50 24 E.	S. L.
Jan. 10.	Pulo Dinding	4 12 47	100 32 52	7 31·2	8·117	8·187	1 48 34	S. L.
Jan. 20.	Pulo Penang	5 25 36	100 24 38	4 52·8	8·159	8·189	1 48 48	S. L.
Feb. 5 to 12.	Nicobar	9 10 12	92 48 23	1 14·8 N.	8·155	8·157	1 53 21	S. L.
Feb. 17.	Noncowry Harbour	8 01 42	93 39 20	0 54·4 S.	......	......	....	U.
Feb. 19.	Bompoko	8 14 05	93 19 20	0 22·9	......	......	....	S. L.
Mar. 26.	Hastings' Island	10 06 45	98 21 15	4 19·0 N.	8·1772	8·200	2 13 10	S. L.
April.	Moulmein	16 29 46	97 45 30	17 45·6	8·1186	8·525	2 20 25	S. L.
July and August.	Madras	13 04 09 ?	80 16 00	7 34·2	8·0784	8·149	0 56 08	S. L.

* Mount Ophir, about 6000 feet high.

TABLE I.

Observations at Sea.

Abstract of Three Hourly Observations made at Sea.

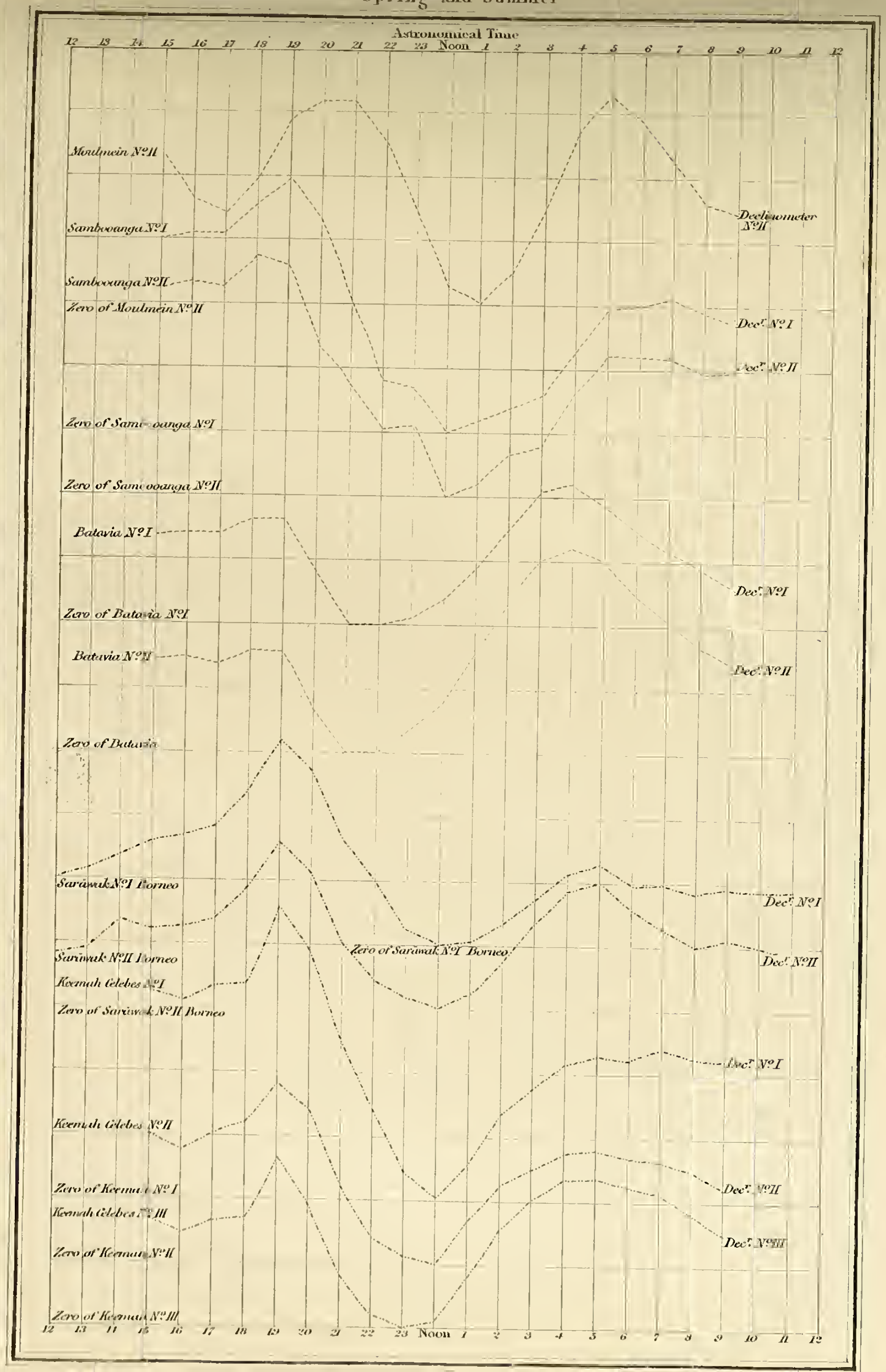
Astronomical Mean Time.	15.	18.	21.	Noon.	3.	6.	9.	Mean.
Observations made during the Month of April, 1848, corresponding to a Mean Latitude of 2° 42′ N.; Mean Longitude 108° 03′ E. Mean date April 27.								
Dry Thermometer, mean of 5 days	83·4	82·7	83·9	86·5	88·3	85·0	84·4	84·9
Wet Thermometer, mean of 5 days	79·5	79·2	79·1	80·5	82·0	79·3	79·8	79·9
Standard Thermometer, mean of 5 days	83·5	83·2	83·6	86·2	88·0	85·4	84·5	85·0
Temperature of the Air, mean of 5 days	......	83·4	83·8	85·0	86·8	......	......	84·8
Temperature of the Sea, mean of 3 days	......	83·9	84·3	85·8	86·5	......	......	85·1
Observations made during the month of May, 1848, corresponding to a Mean Latitude of 7° 07′ N.; Mean Longitude = 119° 50′ E. Mean date May 15.								
Dry Thermometer, mean of 12 days	83·1	82·7	84·9	88·1	89·2	86·3	84·6	85·6
Wet Thermometer, mean of 12 days	79·1	78·7	79·5	81·2	82·0	80·3	79·3	80·0
Standard Thermometer, mean of 12 days	83·4	82·6	84·4	87·5	89·5	87·1	85·0	85·7
Temperature of the Air, mean of 10 days	......	83·2	85·3	87·8	88·1	......	......	86·1
Temperature of the Sea, mean of 10 days	......	85·1	86·1	87·1	87·3	......	......	86·4
Observations made during the month of June, 1848, corresponding to a Mean Latitude of 3° 20′ N.; Mean Longitude 125° 00′ E. Mean date June 10.								
Dry Thermometer, mean of 14 days	81·5	81·3	82·8	85·3	85·6	83·9	82·7	83·3
Wet Thermometer, mean of 14 days	77·5	77·7	78·2	79·5	79·5	78·7	77·9	78·4
Standard Thermometer, mean of 14 days	81·8	81·3	82·4	84·9	85·5	84·6	83·1	83·4
Temperature of the Air, mean of 14 days	81·0	81·8	83·4	85·7	85·3	84·2	......	83·8
Temperature of the Sea, mean of 14 days	82·4	84·1	84·4	85·6	85·2	84·9	......	84·7
Observations made during the Month of July, 1848, corresponding to a Mean Latitude of 2° 55′ S.; Mean Longitude 126° 00′ E. Mean date July 17.								
Dry Thermometer, mean of 22 days	80·5	80·3	81·5	83·7	83·8	82·3	81·7	82·0
Wet Thermometer, mean of 22 days	77·1	77·4	77·0	78·4	78·3	77·6	77·5	77·6
Standard Thermometer, mean of 22 days	80·5	80·2	81·0	83·9	84·0	82·8	82·1	82·1
Temperature of the Air, mean of 22 days	80·8	80·6	81·6	84·2	84·2	82·8	82·2	82·4
Temperature of the Sea, mean of 22 days	80·7	81·8	82·5	83·7	83·5	82·9	82·1	82·5
Observations made during the Month of August, 1848, corresponding to a Mean Latitude of 6° 32′ S.; Mean Longitude 105° E. Mean date August 17.								
Dry Thermometer, mean of 9 days	79·5	79·0	82·0	84·3	83·3	81·9	80·8	81·6
Wet Thermometer, mean of 9 days	77·4	76·6	77·7	78·6	78·4	77·8	76·8	77·6
Standard Thermometer, mean of 9 days	79·3	78·9	81·5	84·2	83·5	81·9	81·1	81·5
Temperature of the Air, mean of 9 days	80·0	79·3	81·6	84·0	83·3	82·7	81·7	81·8
Temperature of the Sea, mean of 9 days	81·2	82·5	84·6	85·1	84·3	84·8	83·6	83·7

Table I.

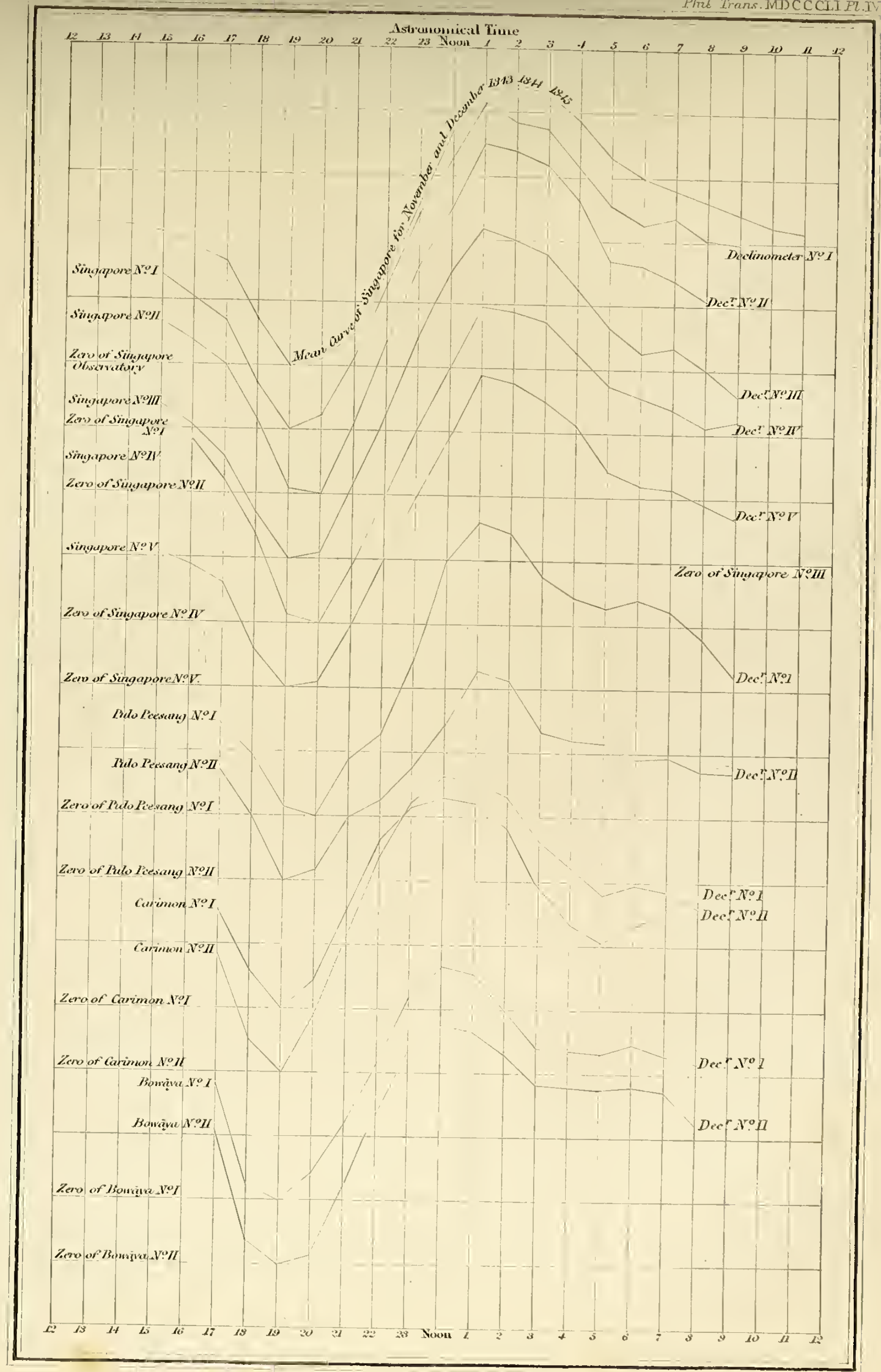
Astronomical Mean Time.	15.	18.	21.	Noon.	3.	6.	9.	Mean.
Observations made during the Month of October, 1848, corresponding to a Mean Latitude of 3° 00′ S.; Mean Longitude 103° 00′ E. Mean date October 10.								
Dry Thermometer, mean of 8 days	80·5	80·2	83·1	86·7	86·7	84·0	81·9	83·4
Wet Thermometer, mean of 8 days	77·1	76·4	78·3	80·0	79·7	78·3	77·0	78·2
Standard Thermometer, mean of 8 days	80·5	80·0	82·4	86·1	86·5	84·3	82·4	83·2
Temperature of the Air, mean of 8 days	80·9	80·5	83·9	87·6	87·1	83·2	82·3	83·8
Temperature of the Sea, mean of 8 days	83·4	84·0	84·4	86·2	86·1	84·7	84·6	84·8
Observations made during the Month of November, 1848, corresponding to a Mean Latitude of 0° 46′ N.; Mean Longitude 105° 20′ E. Mean date November 3.								
Dry Thermometer, mean of 4 days	81·4	82·2	81·7	83·1	84·8	83·8	82·4	82·8
Wet Thermometer, mean of 4 days	78·6	78·0	77·1	78·5	79·2	78·5	77·6	78·2
Standard Thermometer, mean of 4 days	81·2	82·0	81·2	82·9	83·9	84·2	82·5	82·5
Temperature of the Air, mean of 4 days	82·1	82·3	82·3	83·5	85·3	84·1	82·2	83·1
Temperature of the Sea, mean of 4 days	83·6	83·0	84·8	85·0	85·1	84·3	83·8	84·3
Observations made during the Month of February, 1849, corresponding to a Mean Latitude of 9° 00′ N.; Mean Longitude 92° 48′ E. Mean date February 20.								
Dry Thermometer, mean of 10 days	80·4	79·9	82·2	84·3	83·5	82·4	81·0	81·9
Wet Thermometer, mean of 10 days	75·8	75·0	75·7	76·9	75·8	75·8	75·4	75·8
Standard Thermometer, mean of 10 days	80·3	79·8	81·5	83·9	83·5	82·7	81·4	81·8
Observations made during the Month of March, 1849, corresponding to a Mean Latitude of 8° 06′; Mean Longitude 97° 34′ E. Mean date March 20.								
Dry Thermometer, mean of 15 days	83·1	82·4	84·4	86·8	87·4	84·8	84·1	84·7
Wet Thermometer, mean of 15 days	78·3	77·9	78·7	79·7	80·4	78·9	78·9	79·0
Standard Thermometer, mean of 15 days	83·0	82·3	83·9	86·3	87·4	85·1	84·0	84·6
Temperature of the Air, mean of 5 days	83·6	83·2	85·0	87·3	88·1	85·6	84·3	85·5
Temperature of the Sea, mean of 5 days	84·5	84·2	84·9	85·6	85·3	84·7	84·5	84·7
Observations made during the Month of April, 1849, corresponding to a Mean Latitude of 12° 25′ N.; Mean Longitude 97° 34′ E. Mean date April 4.								
Dry Thermometer, mean of 6 days	83·0	82·7	84·4	87·7	88·6	86·1	84·4	85·3
Wet Thermometer, mean of 6 days	78·3	78·0	79·3	80·9	81·1	80·3	78·5	79·5
Standard Thermometer, mean of 6 days	83·0	82·6	83·9	87·2	88·2	86·2	84·6	85·1
Temperature of the Air, mean of 6 days	82·6	82·5	85·0	87·1	88·2	85·3	84·5	85·1
Temperature of the Sea, mean of 6 days	84·2	84·8	85·4	86·3	86·3	85·6	84·0	85·3

Observation of the Magnetic Declination at various Stations in the Eastern Archipelago

Spring and Summer



Winter



J. & C. Walker Sculp.t

Scale of 1' of Arc to 0.35 of an Inch

The Curve Rising denotes a movement of the North Pole of the Magnet Eastward

Explanation. Winter Spring Summer

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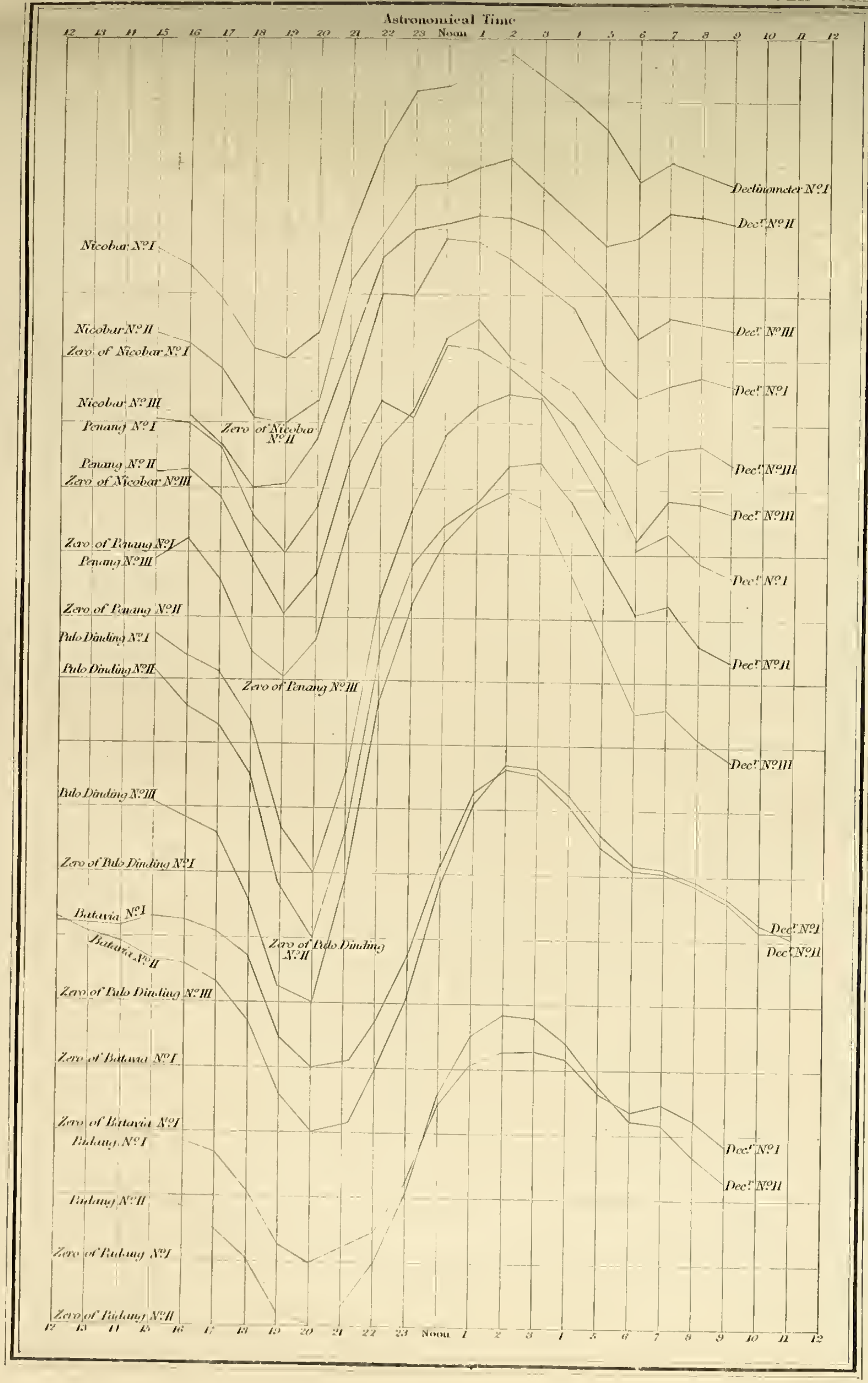

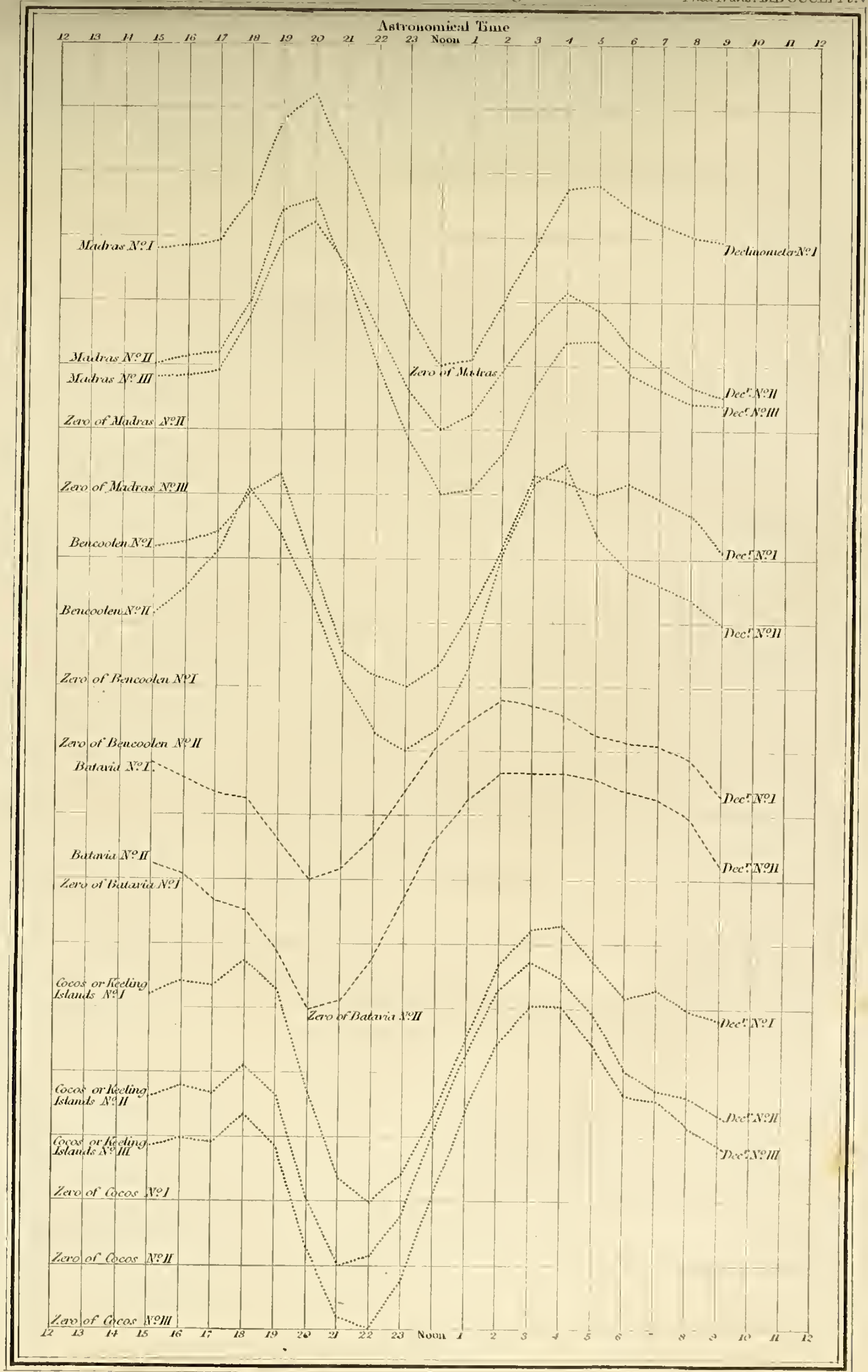

J. & C. Walker Sculpt.

Scale of 1′ of Arc to 0·35 of an Inch

The Curve rising denotes a movement of the North Pole of the Magnet Eastward

Explanation ⋀ Winter ⋀ Spring ⋀ Autumn

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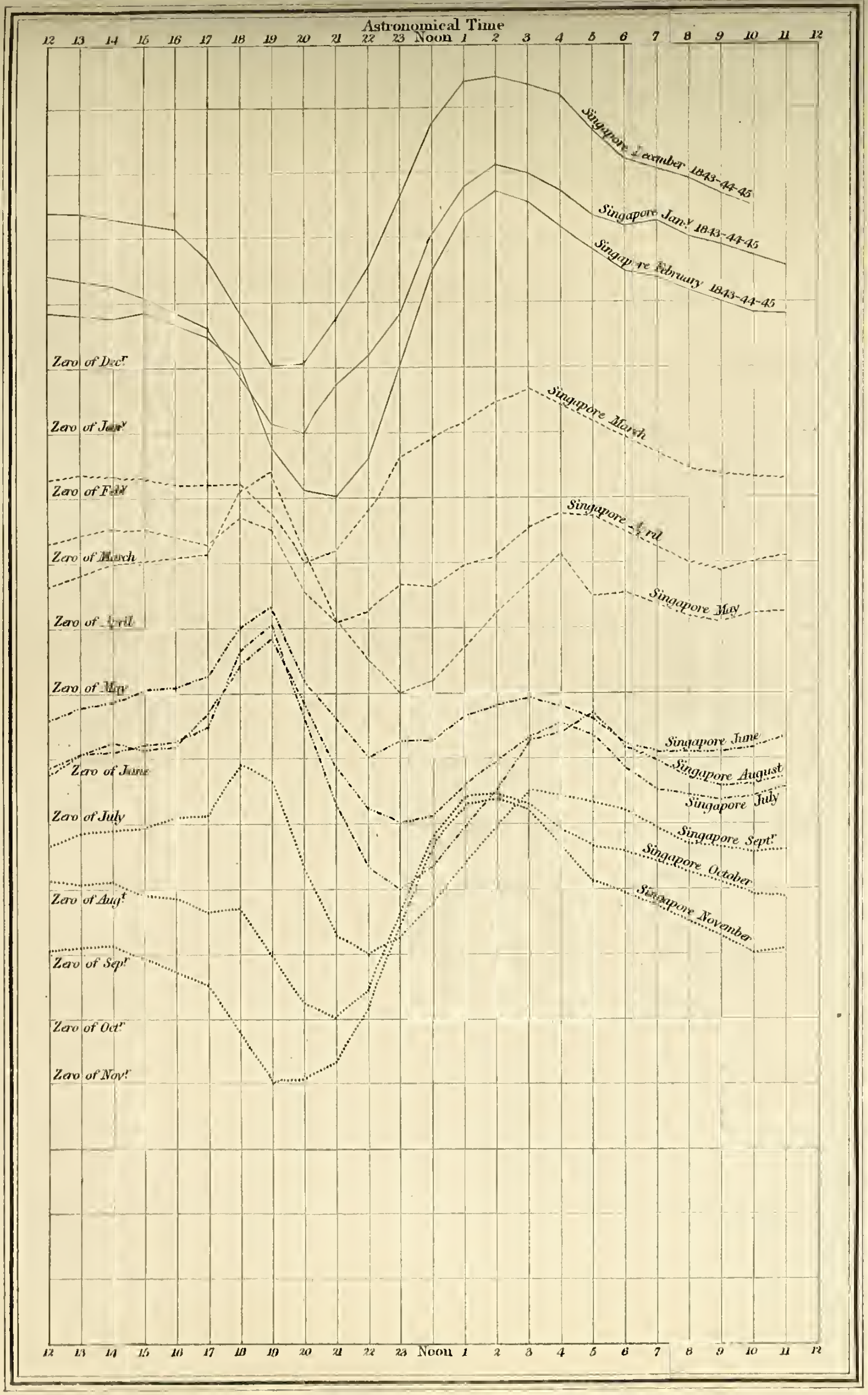
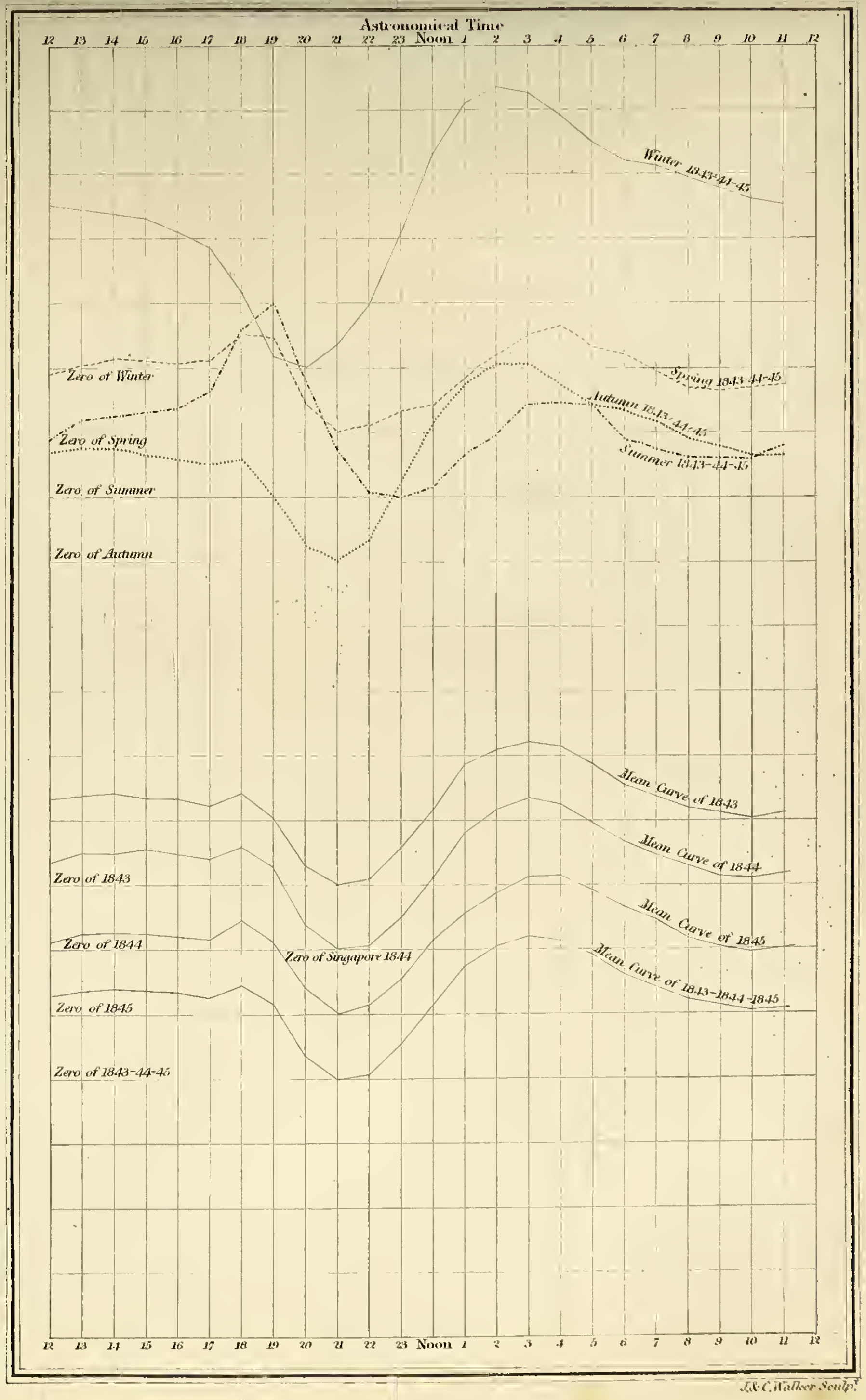
Mean Monthly Curves



Mean of each of the four Seasons, and of each year, and of the General mean.



J.& C. Walker Sculpt

Scale of 0·68 of Arc to 0·35 of an Inch.

The Curve Rising denotes a movement of the North Pole of the Magnet Eastward

Explanation : ╱╲ Winter ╱╲ Spring ╱╲ Summer ╱╲ Autumn

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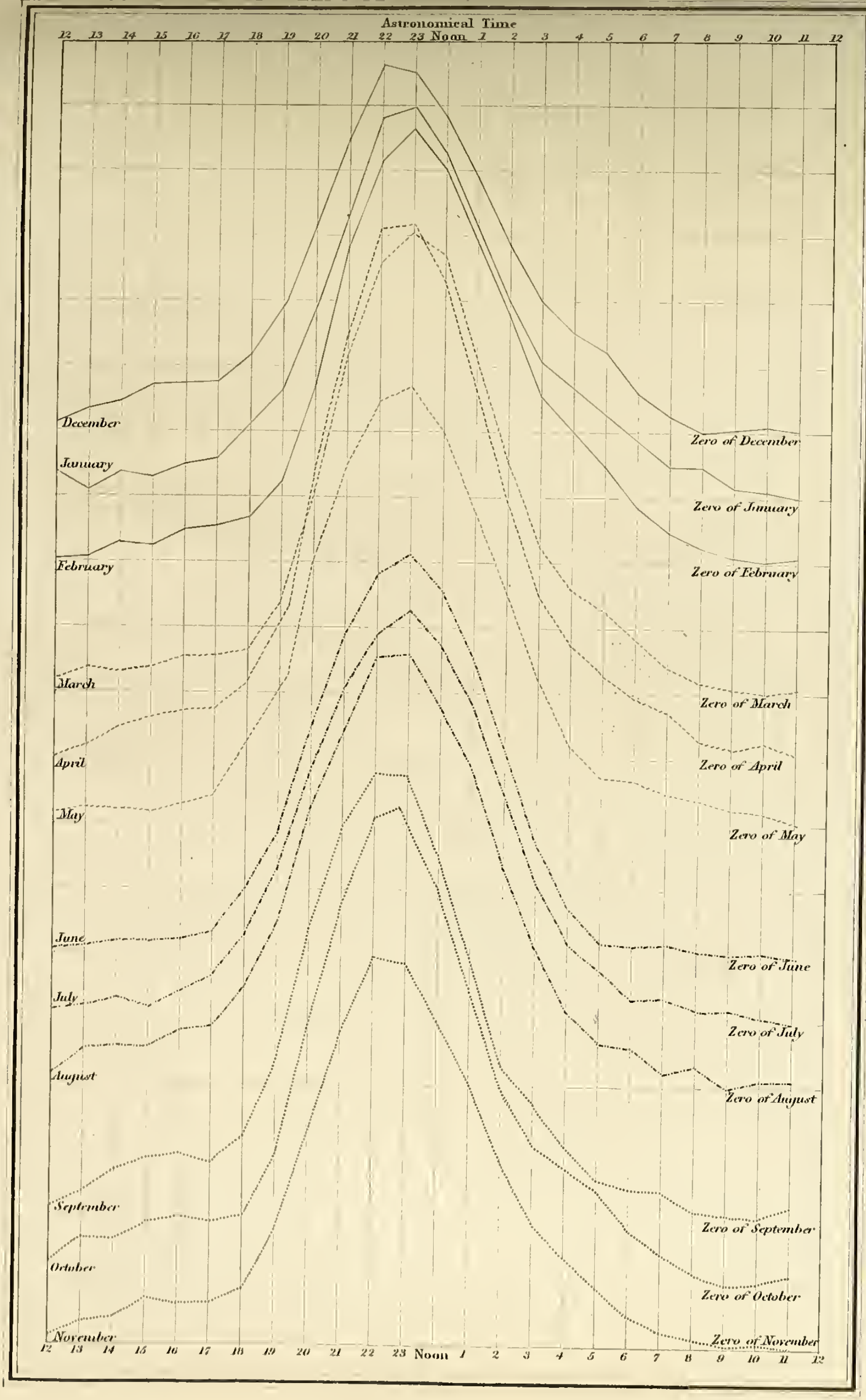
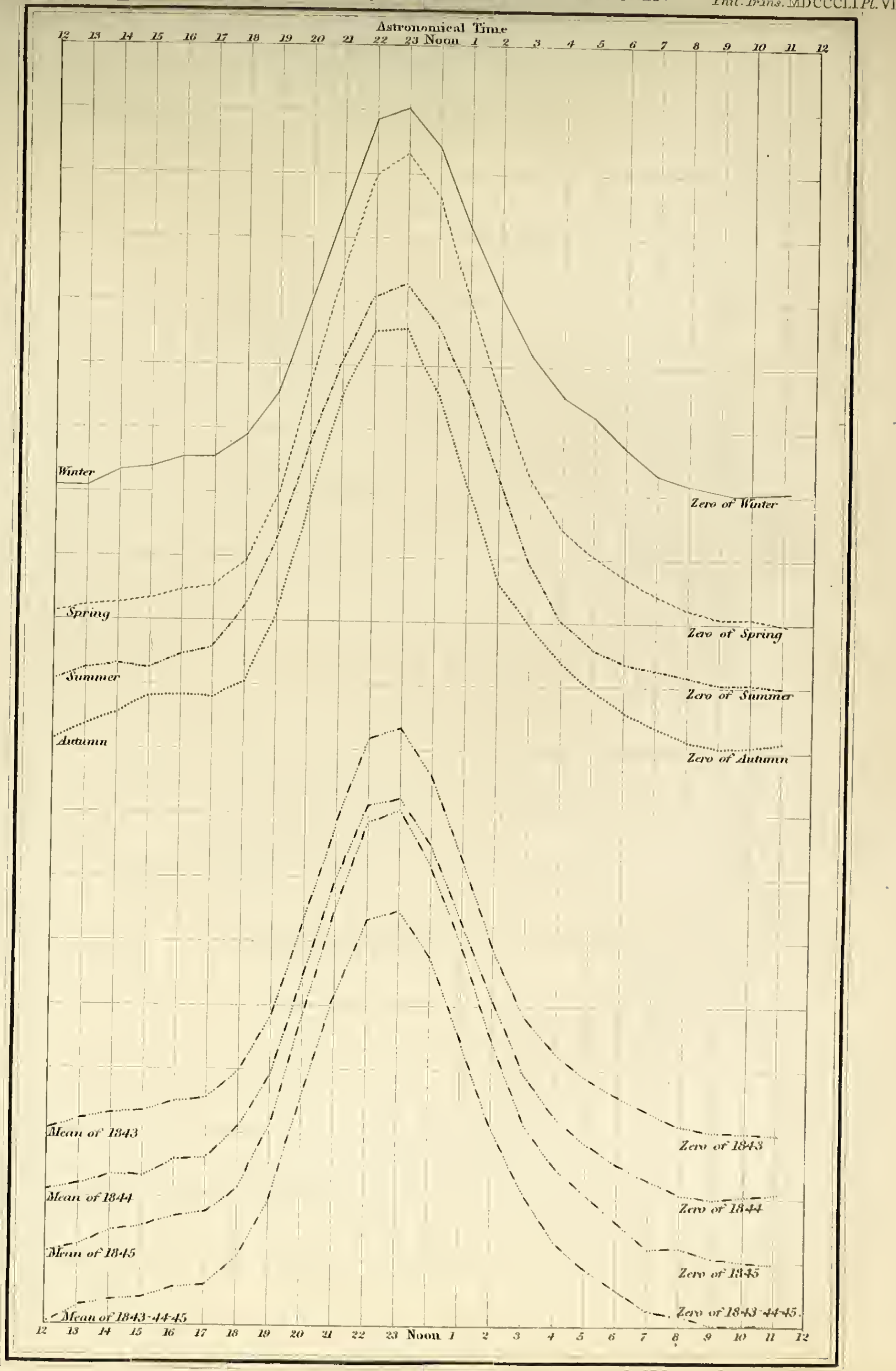
Mean of each Month for three Years.



Mean of each of the four Seasons for three Years, the mean of each year, and the mean of the three Years.



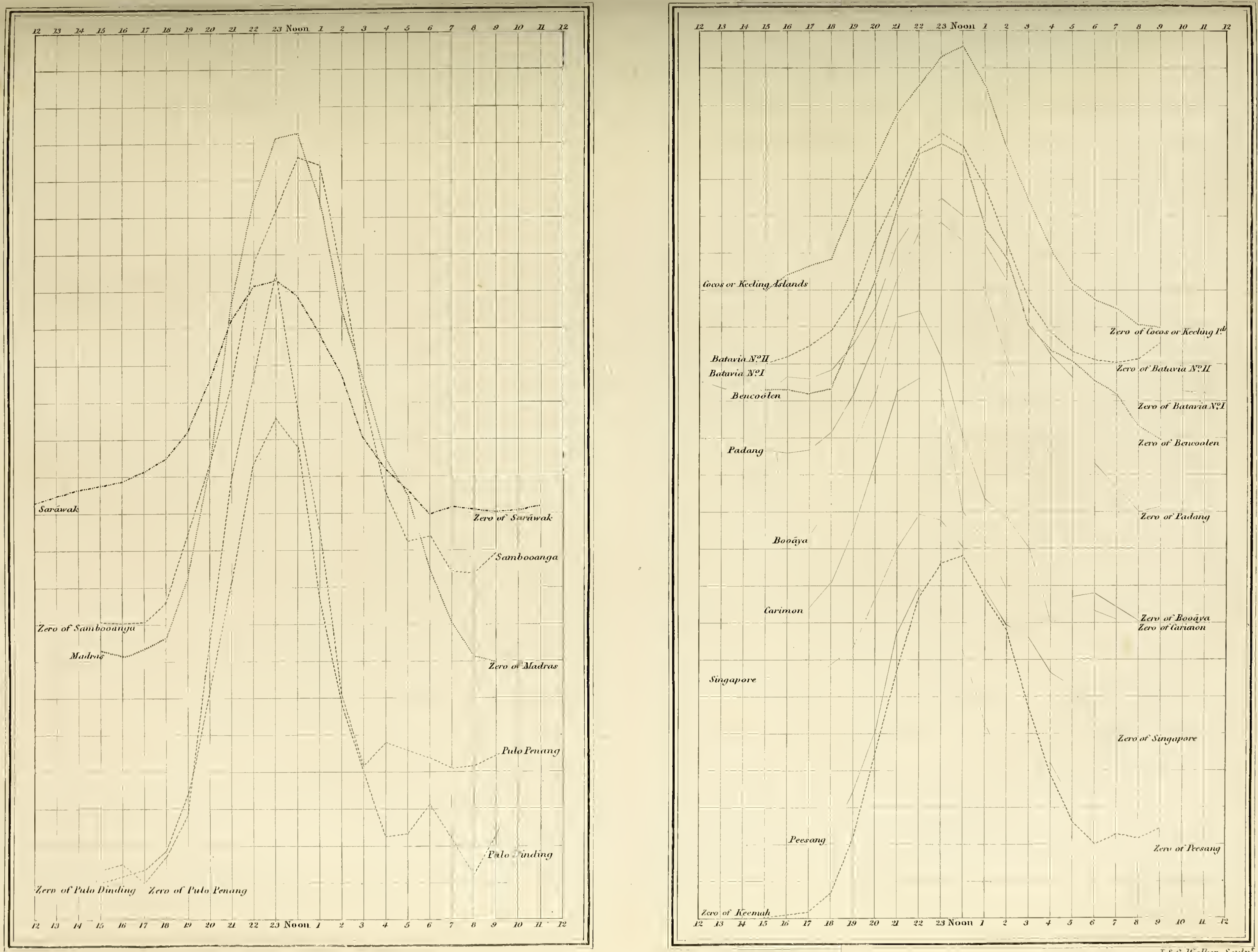
One Scale Division ·000197 of the Force to 0·35 of an Inch

The Curve Rising denotes an increase of Horizontal Force

Explanation : Winter Spring Summer Autumn

J. & C. Walker Sculpt.

BRITISH MUSEUM NATURAL HISTORY



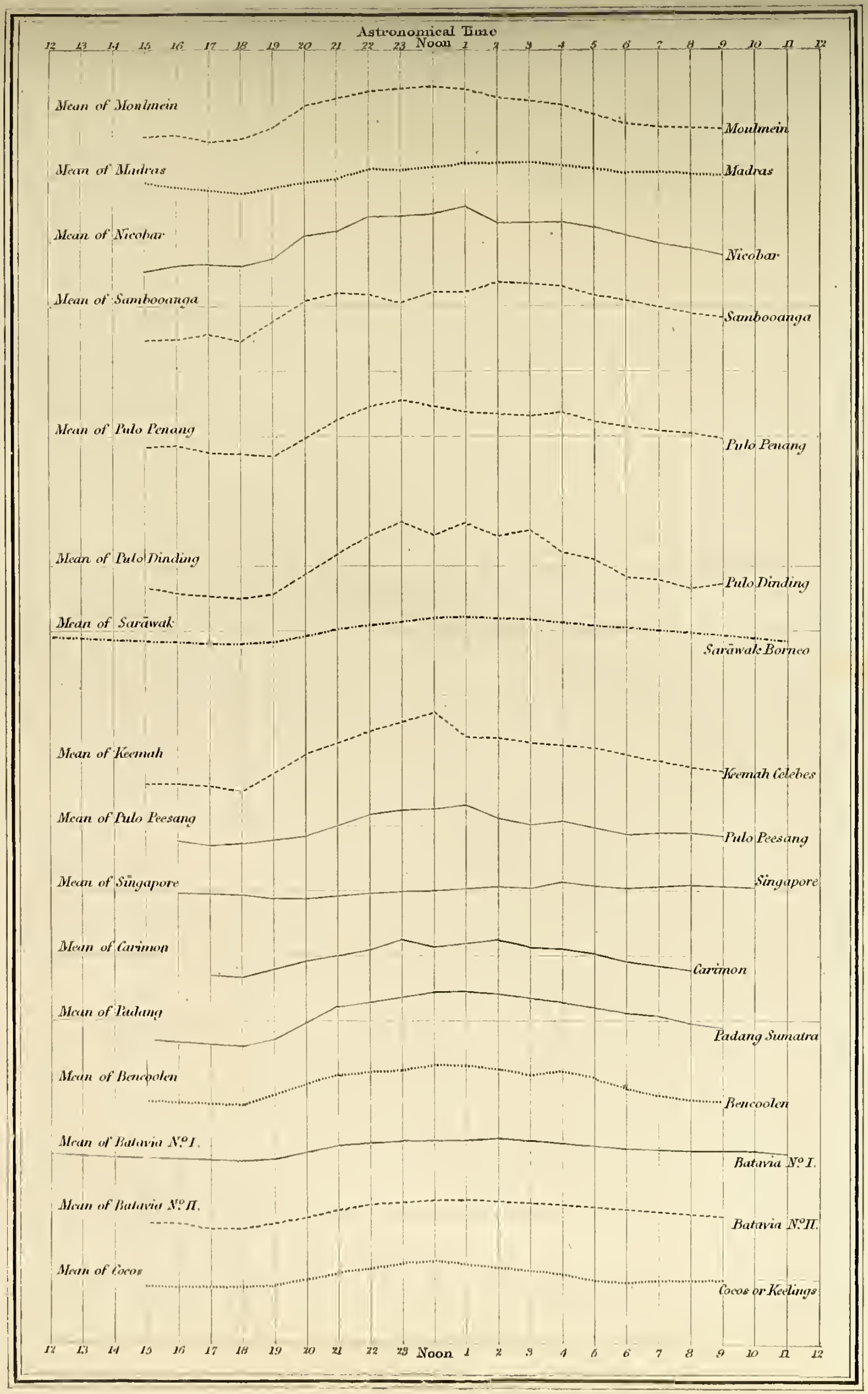
J. & C. Walker Sculpt.

One Scale Division (=0002402 of the Force) to 0.29 of an Inch

The Curve Rising denotes an Increase of Force

Explanation: Winter Spring Summer Autumn

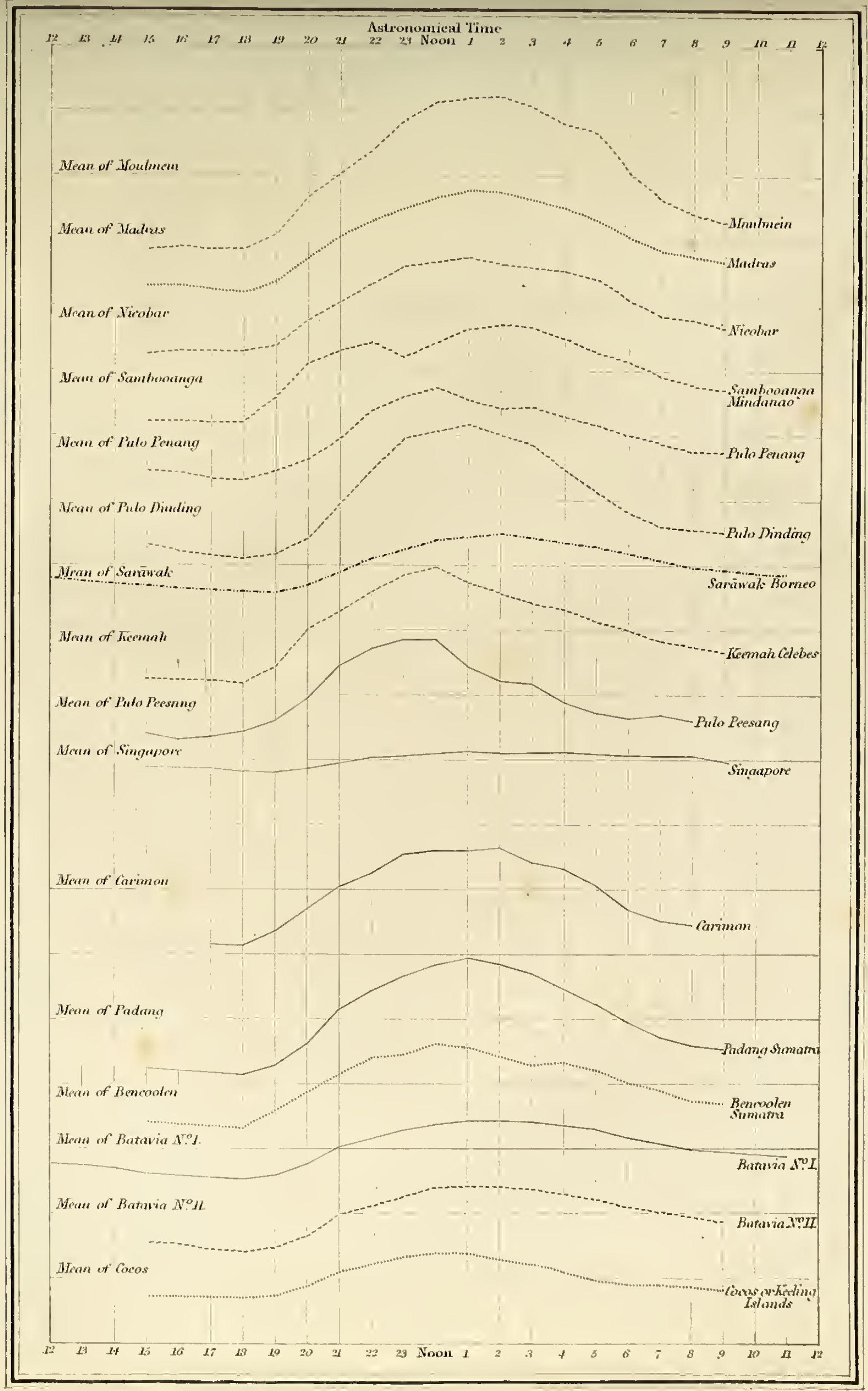
BR[illegible] [illegible]SEUM



Scale of 10° of Wet Bulb to 0·35 of an Inch

The curve rises with increase of Temperature

Explanation: .... Summer ---------- Spring .... Autumn ⁄\ Winter



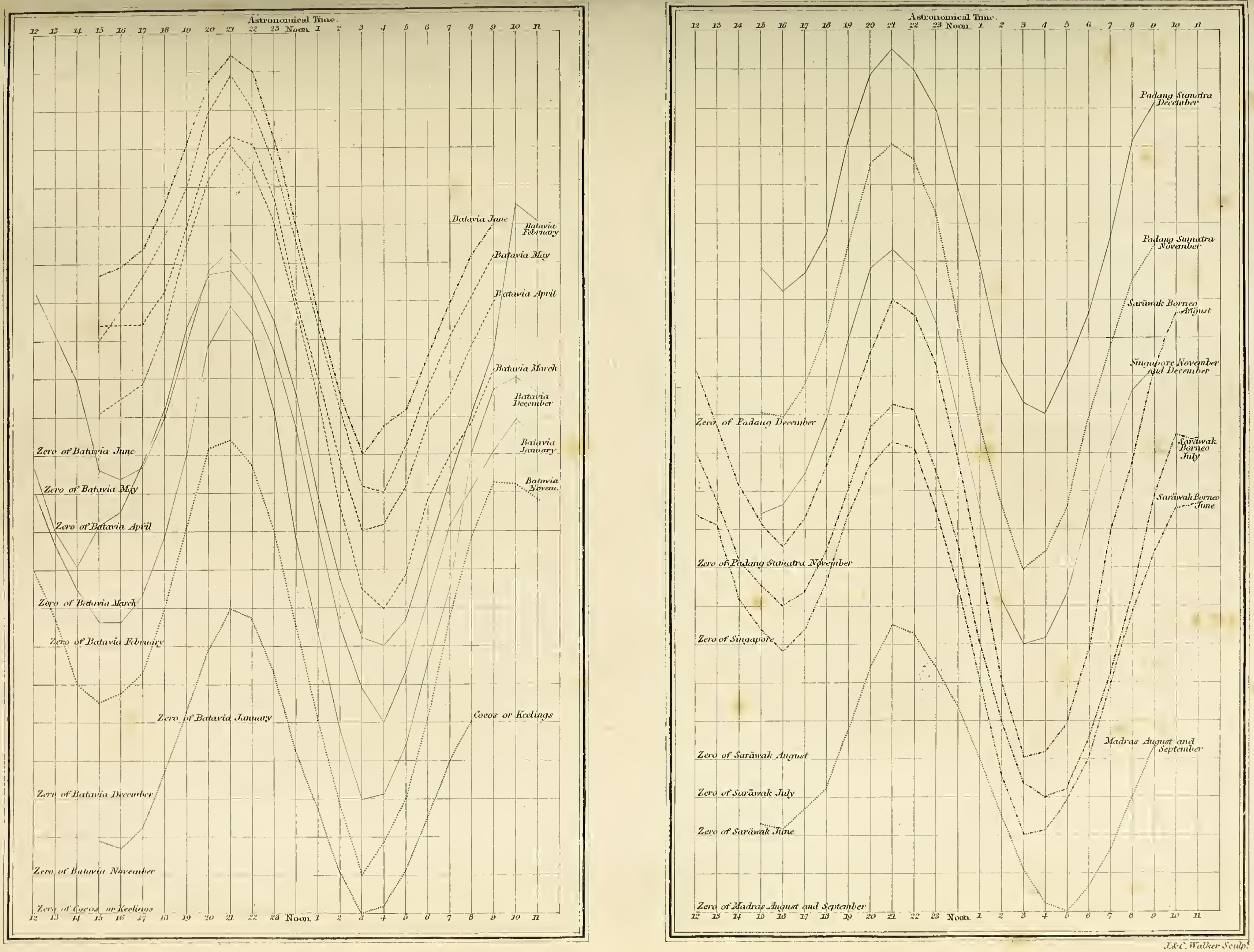
J.&C. Walker Sculp.t

Scale of 10° of Temp.e to 0·35 of an Inch

The curve rises with increase of Temperature

Explanation: .... Summer ---------- Spring .... Autumn ⁄\ Winter

B[illegible] NAT[illegible]AL [illegible]

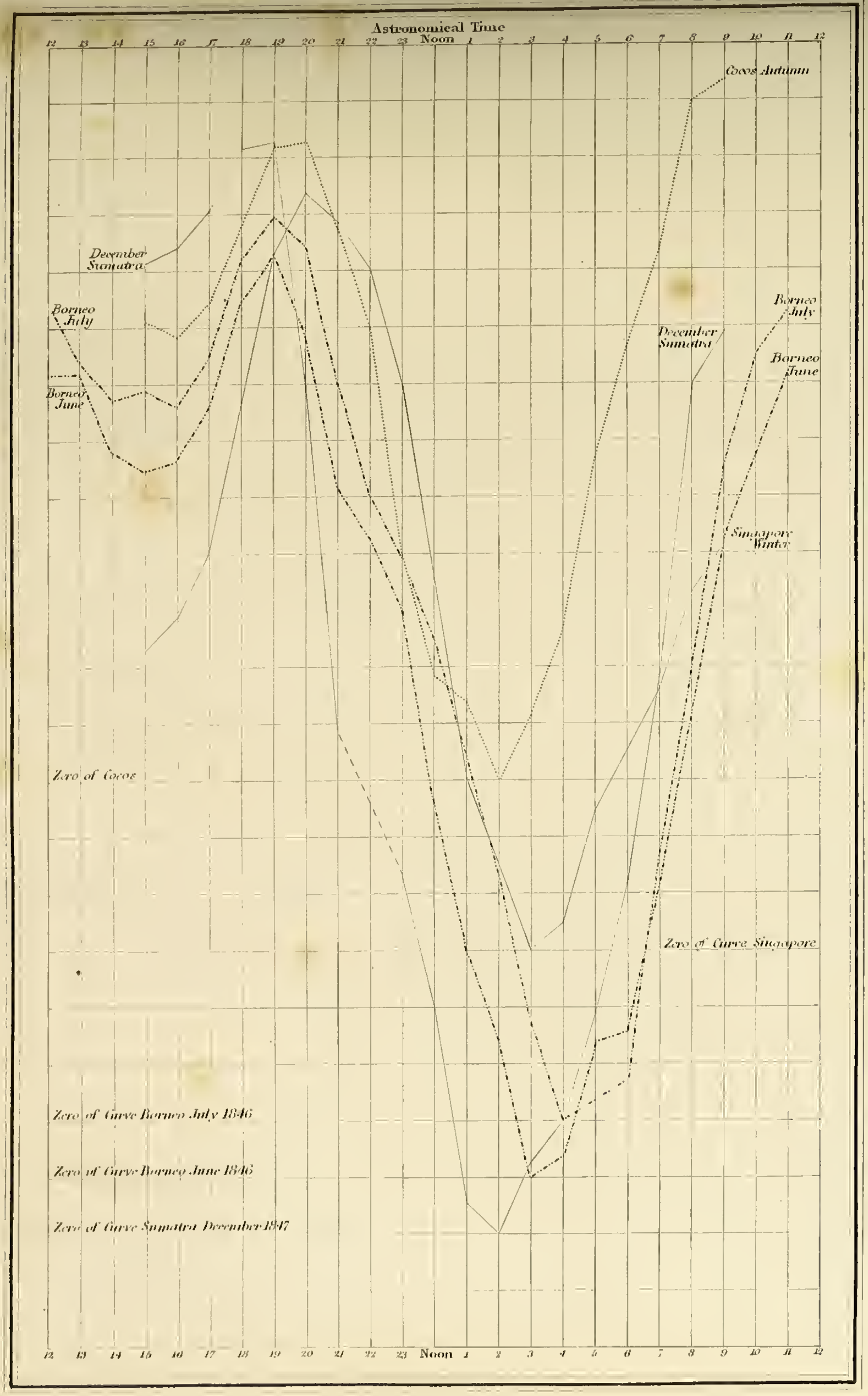


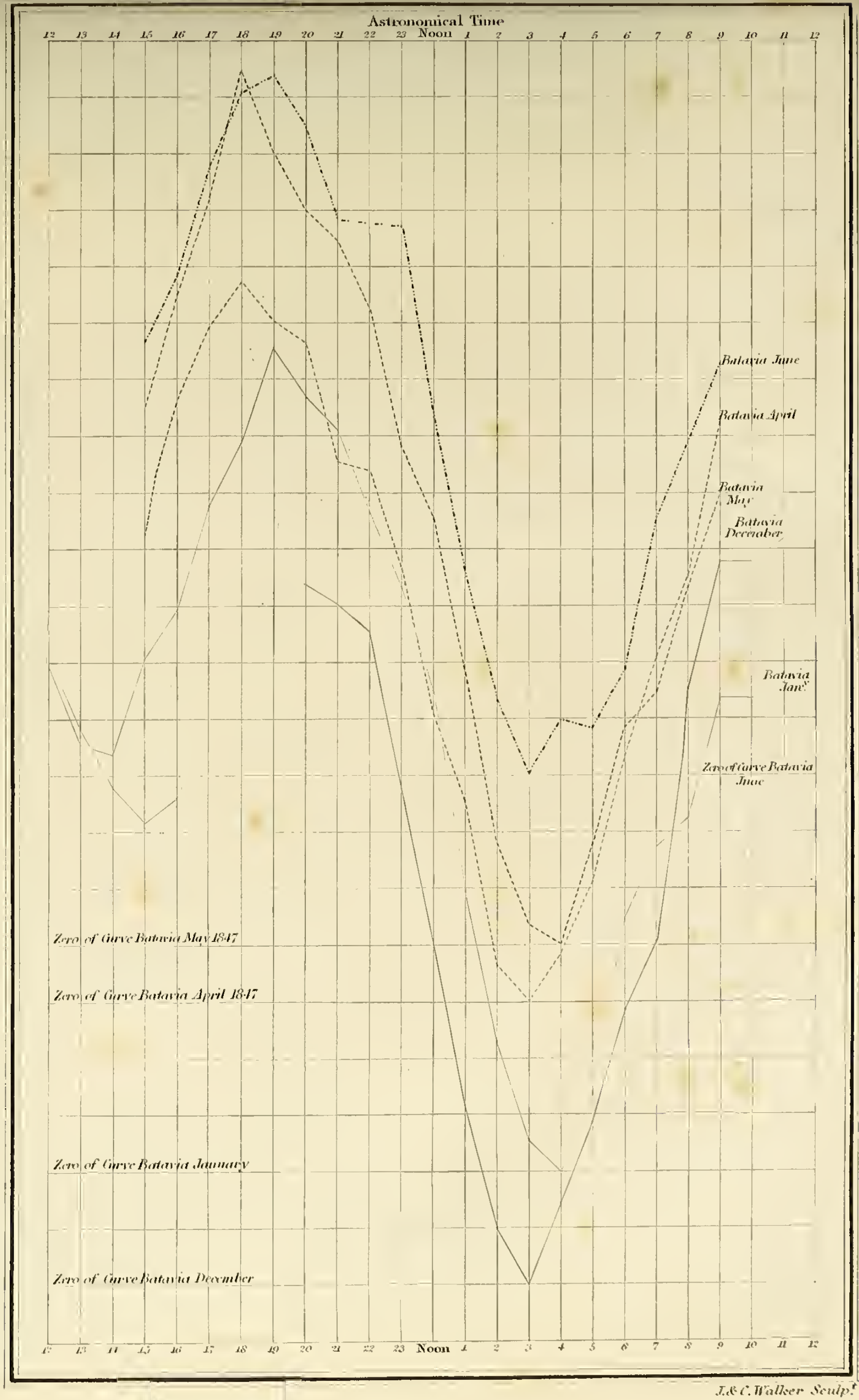
J.&C. Walker Sculp.

Scale of 0·010 of an Inch of Barometric Pressure to 0·30 of an Inch linear measure

Explanation, ‒·‒·‒·‒ *Summer* - - - - - - *Spring* ·········· *Autumn* ⁓ *Winter*

NATURAL





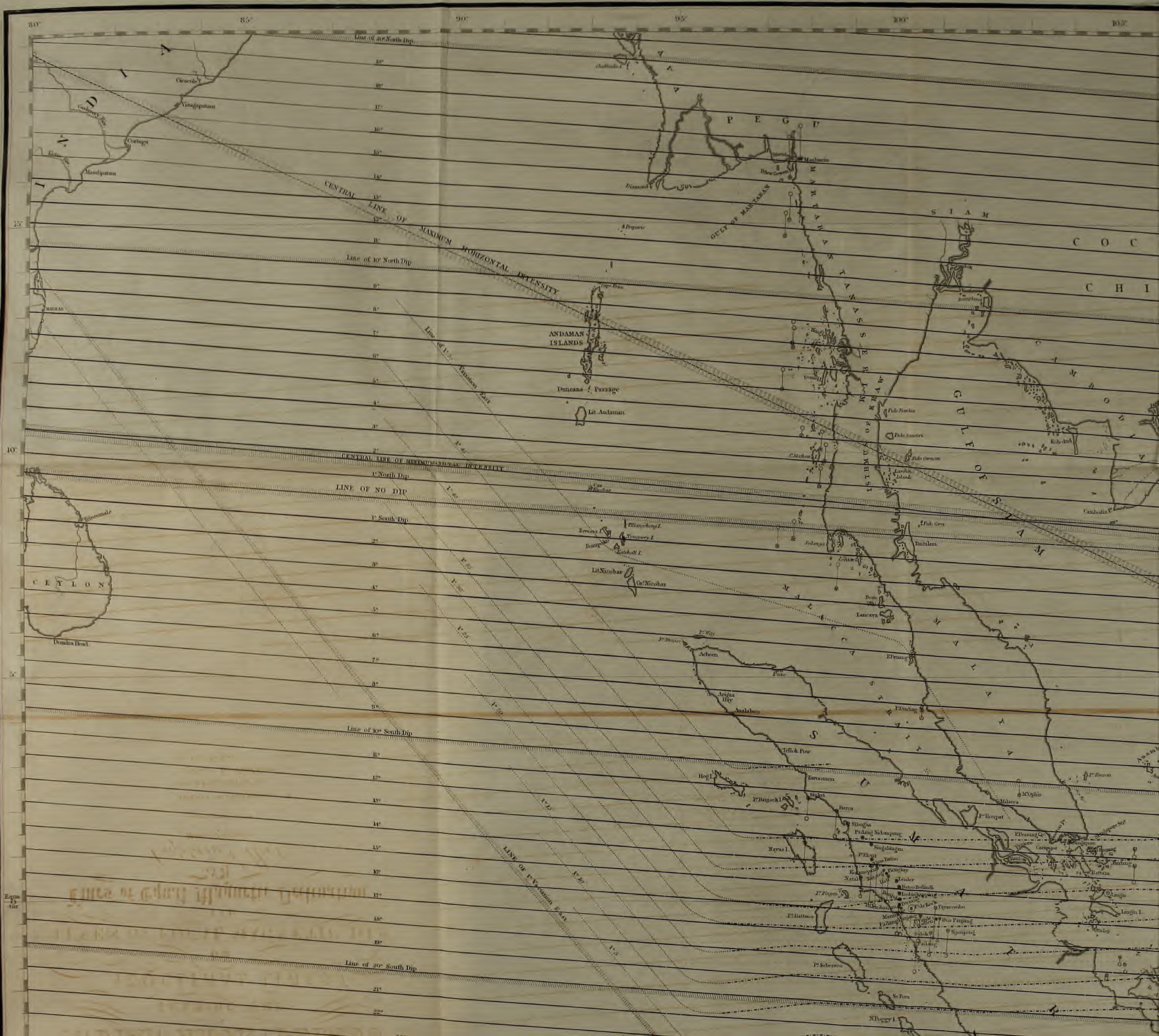
J. & C. Walker Sculp.

Scale of ·010 of an Inch of Pressure of Mercury to 0·30 of an inch linear measure.

The Curve rises with increase of Pressure.

Explanation : /\ Winter. \/\--- Spring. ../\/ Summer. ..../\..... Autumn.

BRITISH MUSEUM
NATURAL HISTORY.


80°
85°
90°
95°
100°
105°
15°
10°
5°
Equa-tor
Line of 20° North Dip
19°
18°
17°
16°
15°
14°
13°
12°
11°
Line of 10° North Dip
9°
8°
7°
6°
5°
4°
3°
2°
1° North Dip
LINE OF NO DIP
1° South Dip
2°
3°
4°
5°
6°
7°
8°
9°
Line of 10° South Dip
11°
12°
13°
14°
15°
16°
17°
18°
19°
Line of 20° South Dip
21°
22°
CENTRAL LINE OF MAXIMUM HORIZONTAL INTENSITY
CENTRAL LINE OF MINIMUM TOTAL INTENSITY
Line of 1° 50' Variation East
1° 45'
1° 40'
1° 35'
1° 30'
1° 25'
1° 20'
1° 15'
1° 10'
LINE OF 1° Variation East
1° 5'
INDIA
Ciracole
Viragapatam
Godavery Riv.
Coringa
Kistna Riv.
Masulipatam
MADRAS
CEYLON
Trincomale
Dondra Head
AVA
Cheduba I.
PEGU
Diamond I.
Maulmein
Martaban
GULF OF MARTABAN
MARTABAN
TANASSERIM
Preparis
ANDAMAN ISLANDS
Cape Price
Duncans Passage
Lit. Andaman
Car Nicobar
Tillanchong I.
Terressa I.
Nancowry I.
Bompoka
Katchall I.
Lit. Nicobar
Gt. Nicobar
Domel I.
C. Mathew
ISTHMUS OF KRAW
SIAM
Bangkok
Pulo Panjang
Pulo Aur
Pulo Carnam
Laconia Islands
Pulo Gora
Pantalam
Salanga
Lontar
Trutto
Lancava
P. Pinang
P. Dinding
GULF OF SIAM
COCHIN CHINA
CAMBODIA
Koh-dud
Cambodia Pt.
MALACCA STRAIT
MALAYA
P. Way
P. Brasse
Acheen
Pase
Arigas Bay
Analaboo
SUMATRA
Tellok Pow
Baroomon
Hog I.
P. Bangack I.
Singkel
Baros
Siboglia
Padang Sidempeng
Nayas I.
Malacca
Mt. Ophir
P. Boupat
P. Timoan
Singapore
Batoo
Natal
P. Pinjan
P. Battoos
P. Seberoo
Sa Pora
N. Poggy I.
Lingin I.

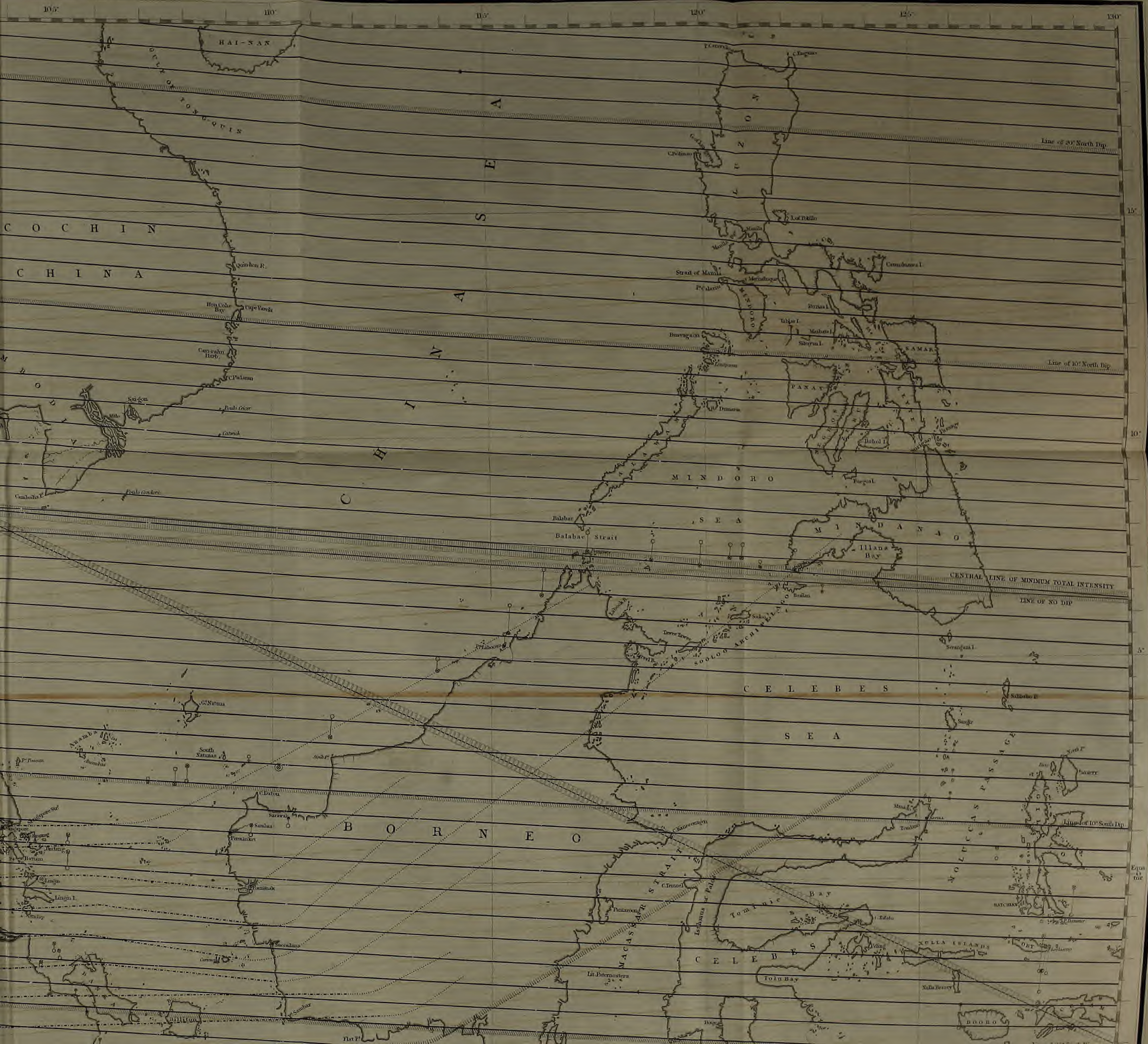

105°
110°
115°
120°
125°
130°
15°
10°
5°
Equator
HAI-NAN
GULF OF TONQUIN
COCHIN CHINA
CAMBODIA
Quin hon R.
Hon Cohe Bay
Cape Varela
Cam-rahn Harb.
C. Padaran
Sai-gon
Mitho
Poulo Ceicer
Catwick
Cambodia Pt.
Poulo Condore
CHINA SEA
LUZON
C. Bojeador
C. Engaño
C. Bolinao
L. of Polillo
Manila
Strait of Manila
Pt. Calavite
MINDORO
Busvagaon
Burias I.
Tablas I.
Masbate I.
Sibuyan I.
SAMAR
Catanduanes I.
PANAY
NEGROS
LEYTE
Bohol I.
Surigao
Fuegos I.
PALAWAN
Dumaran
Line of 20° North Dip
Line of 10° North Dip
MINDORO SEA
Balabac
Balabac Strait
MINDANAO
Illana Bay
Basilan
Sooloo
SOOLOO ARCHIPELAGO
Serangani I.
CENTRAL LINE OF MINIMUM TOTAL INTENSITY
LINE OF NO DIP
CELEBES SEA
Sangir
Salibabo I.
Gt. Natuna
Anamba
Bunbus
Pr. Timoan
South Natunas
Labuan
C. Datou
Sarawak
Sambas
Pontianak
Singapore
Singapore Str.
Bintang
Battam
Lingga
Lingga I.
BORNEO
Banjarmasin
Succadana
Carimata
Lit. Paternosters
Pt. Sambar
Flat Pt.
Billiton
MACASSAR STRAIT
Kaneeoongan
C. Temoel
Pamaroong
CELEBES
Tomini Bay
Tolo Bay
Menado
Kema
Tondano
MOLUCCA PASSAGE
GILOLO
Morty
North Pt.
Line of 10° South Dip
BATCHIAN
OBY
XULLA ISLANDS
Xulla Bessey
BOORO
CERAM

CHART
of the
MAGNETIC SURVEY
OF THE
INDIAN ARCHIPELAGO
SHEWING THE
ISOCLINAL LINES
OR
LINES OF EQUAL MAGNETIC DIP
AND
Lines of Equal Magnetic Declination
BY
Captain Elliot
Madras Engineers.

Stations of Observation
Points Furnished for the adjacent Isoclinal Lines
Central Stations

J A V A S E A
Billiton
P.t Sambar
Flat P.t
Salatan
P. Laut
Lit. Paternosters
Tolu Bay
Xulla Bessey
B O O R O
Line of 20° South Dip.
Bay of Bony
P.t Mandhar
Macassar
Panganşane
Wowony
St Mathews I.
Salayr
Postillions
Engano
Pulo Bay
Telok Betong
Lampong
Anjer
Batavia
Indramayo
Samarang
Bankawa
Souracaya
M A D U R A
Sumenap
J A V A
B A L L Y
LOMBOCK
S U M B A W A
F L O R E S
Ombay
Wetter
T I M O R
Line of 30° South Dip.
LINE OF NO VARIATION
GREAT PATER NOSTERS
Sandal Wood I.
Rotte
5°
10°
105°
Longitude East of Greenwich
110°
115°
120°
125°
130°
Engraved by J. & C. Walker

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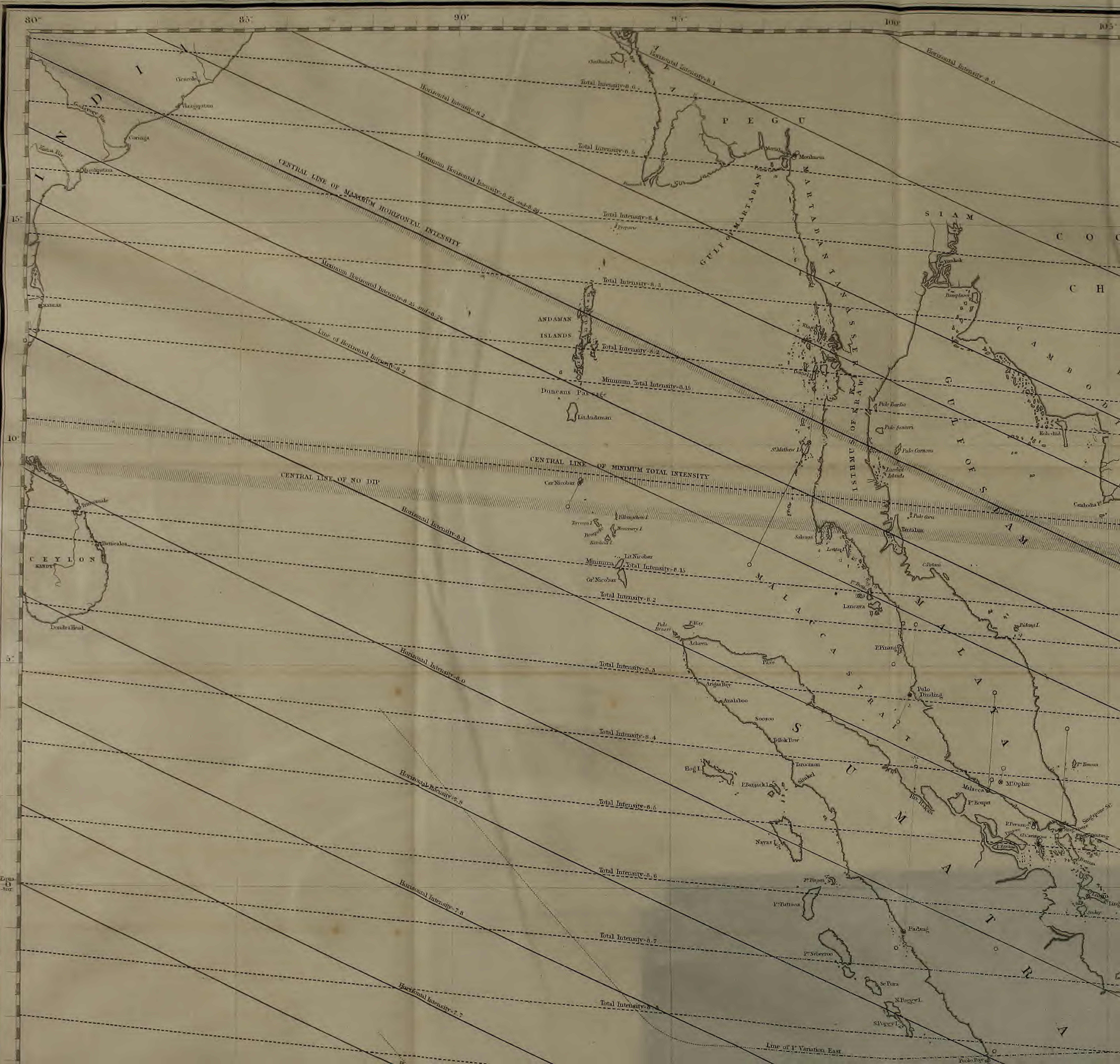
80°
85°
90°
95°
100°
105°
15°
10°
5°
Equa-0-tor
INDIA
Cicacole
Vizagapatam
Godavery Riv.
Coringa
Kistna Riv.
Masulipatam
MADRAS
CEYLON
KANDY
Trincomale
Batticaloa
Dondra Head
PEGU
Cheduba I.
AVA
Moulmein
Martaban
Gulf of Martaban
MARTABAN
TANASSERIM
Preparis
ANDAMAN ISLANDS
Duncans Passage
Lit. Andaman
Car Nicobar
Tillangchon I.
Teressa I.
Bompoka
Nancowry I.
Katchall I.
Lit. Nicobar
Gr. Nicobar
King I.
Domel I.
St. Mathew I.
Isthmus of Kraw
SIAM
Bankok
Bamplasoi
Palo Bardia
Palo Sancori
Palo Carnom
Lardat Islands
Palo Cara
Dintalam
Salanga
Lantar I.
Lancava
Pulo Brasse
P. Way
Acheen
Pase
Arigas Bay
Analaboo
Soosoo
Tellok Pow
Tarooman
Sinkel
Hog I.
P. Banjack I.
Nayas I.
P. Pinang
Pulo Dinding
C. Patani
Pulo Redang I.
Malacca Strait
MALAYA
Malacca
Mt. Ophir
P. Roupat
P. Timoan
Singapore St.
Singapore
Bintang
Battam
P. Persang
Linga
SUMATRA
Padang
P. Battoa
P. Siberoo
Se Pora
N. Pogey I.
S. Pogey I.
Poolo Baÿ
Gulf of Siam
Koh-dud
Cambodia Pt.
COCHIN CHINA
CAMBODIA
Horizontal Intensity = 8.0
Horizontal Intensity = 8.1
Horizontal Intensity = 8.2
Maximum Horizontal Intensity = 8.25 and = 8.26
CENTRAL LINE OF MAXIMUM HORIZONTAL INTENSITY
Maximum Horizontal Intensity = 8.25 and = 8.26
Line of Horizontal Intensity = 8.2
Horizontal Intensity = 8.1
Horizontal Intensity = 8.0
Horizontal Intensity = 7.9
Horizontal Intensity = 7.8
Horizontal Intensity = 7.7
Total Intensity = 8.6
Total Intensity = 8.5
Total Intensity = 8.4
Total Intensity = 8.3
Total Intensity = 8.2
Minimum Total Intensity = 8.15
CENTRAL LINE OF MINIMUM TOTAL INTENSITY
CENTRAL LINE OF NO DIP
Minimum Total Intensity = 8.15
Total Intensity = 8.2
Total Intensity = 8.3
Total Intensity = 8.4
Total Intensity = 8.5
Total Intensity = 8.6
Total Intensity = 8.7
Total Intensity = 8.8
Line of 1° Variation East

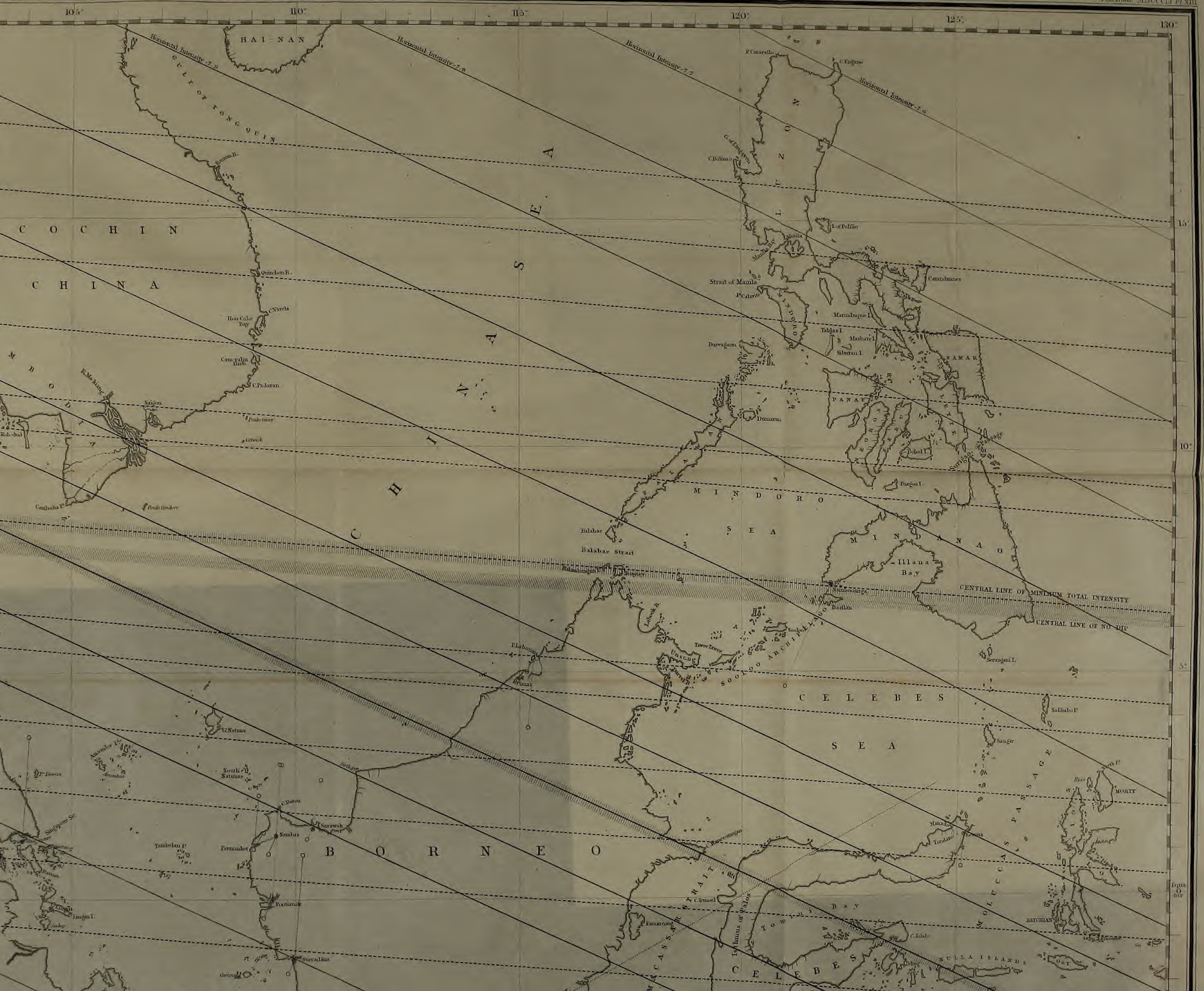
105°
110°
115°
120°
125°
130°
15°
10°
5°
Equator
HAI-NAN
GULF OF TONGQUIN
Horizontal Intensity 7.9
Horizontal Intensity 7.8
Horizontal Intensity 7.7
Horizontal Intensity 7.6
COCHIN
CHINA
CAMBODIA
CHINA SEA
LUZON
MINDORO
PANAY
SAMAR
LEYTE
PALAWAN
MINDORO SEA
MINDANAO
Illana Bay
Balabac
Balabac Strait
CENTRAL LINE OF MINIMUM TOTAL INTENSITY
CENTRAL LINE OF NO DIP
SOOLOO ARCHIPELAGO
CELEBES SEA
MOLUCCA PASSAGE
BORNEO
MACASSAR STRAIT
CELEBES
Tomini Bay
XULLA ISLANDS
BATCHIAN
MORTY
Sangir
Serangani I.
Salibabo I.
P. Caravallo
C. Engano
C. Bolinao
G. of Lingayen
Manila
Strait of Manila
I. of Polillo
Catanduanes
Marinduque I.
Tablas I.
Masbate I.
Sibuyan I.
Burvagaon
Dumaran
Bohol I.
Fuegos I.
Surigao Passage
Samboangan
Basilan
Sooloo I.
Tawee Tawee
Unsang
Labuk B.
P. Labuan
Brunai
Gt. Natuna
South Natunas
Anambas
Tambelan I.
Sarawak
Sambas
C. Datoo
Pontianak
Succadana
Singapore Str.
Lingin I.
Pamarong
C. Temoel
Isthmus of Palos
Menado
Kema
C. Talabu
Quinhon R.
C. Varela
Hon Cohe Bay
Camranh Harb.
C. Padaran
Saigon
R. Mekong
Pulo Condore
Cambodia Pt.
Pulo Obi

CHART of the MAGNETIC SURVEY OF THE INDIAN ARCHIPELAGO

SHEWING THE ISODYNAMIC LINES, OR LINES OF EQUAL HORIZONTAL INTENSITY, AND Lines of Equal Total Intensity

BY

Captain Elliot

Madras Engineers.

Stations of Observation ●

Points furnished for the adjacent Isodynamic Lines ○

Line of 1° Var.
Billiton
J A V A S E A
Telok Betong
Strait of Sunda
Anjeer
Cerson
Batavia
Cheringin
Palamangan
Chiltrand
Wine Coopers Bay
Chilacan
Samadang
Garrut
Chiawe
Ambarawa
Samarang
Japara
Solo
Kediri
Banka
Pekalongan
Surabaya
Bankawi
Samenap
MADURA
Soura
J A V A
BALLY
LOMBOCK
SUMBAWA
FLORES
TIMOR
Great Orange Islands
LINE OF NO VARIATION
Sandal Wood I.
Pt. Salayer
Macassar
Bay of Boney
Pangasane
Wywany
BOURO
CERAM
Salayr
Bonthain
Savu I.
Rottie I.
5°
10°
East of Greenwich
105°
110°
115°
120°
125°
130°

PHILOSOPHICAL TRANSACTIONS.

XIII. *On the Results of Periodical Observations of the Positions and Distances of Nineteen of the Stars in Sir* John Herschel's *Lists of Stars, favourably situated for the investigation of Parallax, contained in Part III. of the Philosophical Transactions for* 1826, *and Part I.* 1827*. *By Lord* Wrottesley, *F.R.S. &c.*

Received November 14, 1850,—Read January 16, 1851.

In these communications, Sir John Herschel shows, that if the component members of a double star occupy a certain position with reference to the pole of the ecliptic, and one of them be supposed to be situated within a given distance from the earth, a change will be periodically produced in the angle of position, and in the distance of the two stars forming the double star, consequent on the motion of the earth in her orbit; that the maximum of the change in the angle of position will occur at two periods of the year distant from each other about six months; and he gives formulæ by which the epochs at which that maximum occurs may be computed, and by which the amount of parallax due to a given change in the angle of position may be also found for each star; also lists of stars favourably situated for the investigation of that element, with the times of the year at which they should be observed, and the amount of parallax, which an observed change of 30′ in the angle of position would indicate in the case of each star.

On the erection of my observatory in the autumn of 1842, comprising among its instruments an equatoreal of very considerable power, I determined to employ it in the observations of the double stars contained in these lists, with the view of ascertaining whether they exhibited such decided differences in their positions, when observed at the proper periods, as to give good grounds of hope that some definite conclusion might be arrived at, as to the existence of a parallax in the objects observed, capable of being measured, or at the least, confidently announced as subsisting in fact.

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* I have to acknowledge my obligations to Mr. Main of the Royal Observatory, Greenwich, for many valuable suggestions during the preparation of this communication for the press.

In conducting the observations, however, difficulties arose that had not been anticipated: Sir John Herschel's lists contain sixty-nine stars; many of these, at the periods announced in the lists as proper for observation, if observed at all, must be observed at distances from the meridian too great, when the delicate nature of the inquiry is considered; many of them, having south or small northern declinations, are near the horizon when the proper period for their observation arrives. Another very serious impediment existed in the obligation imposed of obtaining half of the measures in the early morning hours; the observer, if employed in the observatory on the preceding night, was sometimes fatigued and unequal to the task; heavy fogs frequently came on at that time, and an enormous deposit of dew on the interior surface of the object-glass often seriously incommoded the observer; an evil which, until an opening was made in the tube near it, was irremediable, since the use of dew-tubes failed in preventing it.

To these and other causes it is owing, that after more than six years devoted to this course of observation, I am compelled to apologise for the meagre results which, for reasons about to be mentioned, I have still ventured to lay before the Royal Society in their present shape. Of sixty-nine stars I have only obtained observations of forty-eight, and of these forty-eight, twenty-nine have only been observed at one period of the year.

It is a most discouraging feature in this class of observations, that, however numerous and trustworthy the measures obtained at one period of the year may be, there may still be a failure to procure, at the expiration of six months from their date, measures worthy to be compared with them; and the function of the parallax, being the difference between the two results, the value of that element is of course affected by the whole amount of error with which either result is charged.

It has often happened that a star has been observed at one of the assigned periods, and that no corresponding observations have been procured at the expiration of six months, or the next succeeding period; thus, for example, calling the first epoch in the year at which the star is marked for observation, the *early*, and the second the *late* period, a star has been observed two or more times successively at the early period, when no corresponding observations could be procured at the following late period.

The question then naturally occurs, whether the communication of the measures actually obtained may not be deemed premature. I consider, however, that I have proceeded sufficiently far to demonstrate the impolicy of further perseverance, with the means at my command; the rather that instruments are now erected both at Liverpool and Oxford, which are pre-eminently suited to this class of observations, and therefore it would be only a waste of time and force, which may be more profitably employed in other ways, to devote any further attention to the inquiry.

I proceed, therefore, without further apology, to describe the means employed, the mode of employing them, and the results obtained.

The instrument employed was an equatoreally mounted telescope of 10 feet 9 inches focal length, with an object-glass of $7\frac{3}{4}$ inches clear aperture, of which the flint-glass is by Guinand, and the crown glass English, the whole having been finished and perfected by Dollond.

This telescope is mounted in the manner usually adopted by the opticians of this country in a fixed observatory, in the immediate vicinity of my residence in Staffordshire; the polar axis is formed of four mahogany planks 14 feet 3 inches long and 10 inches square in the middle, the pivots of which are of hard bell-metal, and rest above and below on Y^s attached to large and solid stone piers, which are supported by a foundation of brick-work, joined with cement, and formed into a solid mass of great extent by filling up the space enclosed by an outward circuit of brick with stones and mortar pounded together: this mass of brick-work and stone extends beyond the equatoreal room, and forms also the support of the piers of a 5-foot transit.

The Declination and the Hour Circle are each 3 feet in diameter; the two verniers of the former read off to $10''$ in space, and that of the latter to seconds of time. To the telescope there is attached a parallel-wire micrometer with one equatoreal fixed, and two moveable wires; the screw heads are divided into 100 parts; the micrometer is provided with the usual position circle, graduated on silver, with its vernier which reads to $6'$ in space. The value of one part of the micrometer first employed was $0''\cdot15628$, but from the 1st of January 1847 the value $0''\cdot15641$ was used, the first having been determined by Mr. Beaumont, the former possessor of the instrument, and the latter by myself. There are six eye-tubes that can be used with the micrometer, with powers varying from 85 to 820, but the power almost invariably used in the observations about to be described was 450; one of 320, and sometimes a lower power, was occasionally, but very rarely, employed, and when this occurs a notice to that effect will be found in the Table containing the results of observations subjoined. The telescope is provided with a clock-work motion; the performance of the object-glass, so far as its powers have been tested, leaves nothing to be desired, but the mounting of the telescope, notwithstanding the precautions above mentioned, does not appear to be equally steady with that of some other recently erected equatoreals. Whenever the night admitted of it, ten measures both in position and distance were obtained of each object observed; when in the sequel I speak of a *set* of observations, the term is to be understood as applying to all the observations of a single night, which almost always comprised that number of measures both of position and distance. To each individual measure, whether of position or distance, an arbitrary weight was assigned, and registered at the time of making it, the number 10 being supposed to express a result with which the observer was entirely satisfied, and smaller numbers to denote a less degree of confidence in the value obtained; in point of fact, however, no higher number than 8 seems to have been used, and the weights employed generally range from 4 to 7. The sum of the weights of the individual measures, or the weight of the set, has been divided by 10 prior to its entry in the subjoined tables; while therefore the number 5 should express the weight of a set of average goodness, the number expressive of that weight is reduced in practice to 4. The measures when made are registered in the printed skeleton forms, originally proposed by Sir John Herschel, and adopted, I believe, by almost all observers of double stars in this country. A number of these forms were bound together in a volume, and care was taken to fill up the different columns, so far at least as they refer to measures of position and distance. Whenever the weather permitted, a set of measures was obtained of each double star, on three separate days, at each period of the year marked out as the proper one for observation. The common arithmetical mean was used in taking the average of the partial measures, comprising each set, without taking the arbitrary weights into account. At the commencement of the series, the zero of the position circle was frequently determined; but it was found to undergo no alteration that might not be attributed to error of observation; from that time it became the practice to ascertain it about every two months; but it was never found to vary more than about 2′, a quantity very much within the error of observation in determining an angle, as will appear in the sequel; no zero was required for distance, as it was the practice to take an equal number of positive and negative readings.

The observations were commenced on the 15th February 1843, and terminated the 9th October 1849; and they were made almost exclusively by three gentlemen, who acted successively as my astronomical assistants, during the progress of the work. I have always found, that observations are better made when entrusted to one competent individual, who after a short time gains experience, and a facility of manipulation, which cannot be acquired by one who only occasionally observes; and this uniformity in the mode of observing is particularly desirable, where the quantities to be determined depend on comparisons of observations made at different periods; it was a subject of great regret to me, therefore, that I was compelled to make any change in the staff of my observatory during the course of this investigation, and I only observed myself on a few nights at the time of the first appointment of each assistant.

Mr. Goddard observed from the commencement of the observations to October 2, 1843; Mr. Simms from that time to the 11th of June 1844; and Mr. Philpott, my present assistant, from thence to the conclusion.

The results of the observations are embodied in five tables, and it now remains to explain the manner in which those tables have been formed.

The First Table.—In the first table the stars are arranged in the order of their R.A.'s; and the observations of each day, or sets, follow one another in the order of their date.

An asterisk will be found attached to four of the stars in the list; these are stars, which, on comparing their mean positions as ascertained in the course of this inquiry, with those given by other observers, exhibit changes of such an amount in their angle of position as to afford satisfactory evidence of orbital motion.

This fact being admitted, it is plain that these stars cannot be rendered available in the present inquiry; it was deemed unnecessary therefore to extend to them the method of reduction employed in the case of the other stars; the observations, however, are given with the others in their proper place.

The *third and seventh columns* of the table contain the arithmetical mean of the individual measures, both in position and distance, obtained on the day specified in the first column.

The quantities inserted in *the fourth and fifth columns* headed "probable error" and "computed weight," refer to the positions only, and have been computed from the formulæ

$$P^2 = \frac{0{\cdot}45494}{n(n-1)} \times \text{sum of } \varepsilon^2,$$

$$W = \frac{1}{P^2},$$

where $P =$ probable error of a single set of measures,

$n =$ the number of measures,

$\varepsilon =$ the individual errors,

and $W =$ the weight of the result;

numbers proportional to the computed values of W being inserted in the Table.

The average probable error of all the sets, 211 in number, is $8'{\cdot}98$, and the average weight, 0·0124.

The quantities inserted in the *sixth and eighth columns,* headed "assigned weight," represent the sum of the weights, divided by 10, assigned by the observer to the individual measures of position and distance forming the set, or the arbitrary weights of the sets.

The magnitudes and colours of the stars were noted on each night of observation, and are inserted in the *ninth and tenth columns*; where one colour only is named, it is to be understood as applying to both stars; and where two are specified, the colour of the brighter component, or, in cases of equal brightness, of the star called A, is placed first in order.

The *eleventh column* contains the initial of the observer's name.

The results of each epoch and year are for the sake of distinctness separated by a blank space.

Table I.

Year, Month and Day.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	Colours.	Observer.
γ **Arietis.**										
1843. July 11.	·523	179° 44′	21′·18	2	5	9″·383	5	5—5	White.	G.
Aug. 7.	·597	178 59	14·02	5	7	9·103	7	6—6	Yellowish green.	G.
11.	·608	179 8	9·40	11	8	8·865	8	6—6	Yellowish.	G.
1844. Jan. 13.	·033	179 42	8·66	13	5·3	8·976	5·1	5—5	White.	S.
Feb. 8.	·104	179 43	15·23	4	4·1	8·933	4·2	5—5	White.	S.
1845. Jan. 21.	·055	178 48	13·96	5	3·2	8·720	2·8	5—5	Yellowish.	P.
24.	·063	181 24	8·94	13	2·9	8·943	3·1	5·6—5·6	Yellowish.	P.
Feb. 1.	·085	180 59	11·98	7	1·9	8·837	1·8	5·6—5·6	Yellowish.	P.
17.	·129	179 57	16·02	4	7·1	8·794	7·3	5·6—5·6	Yellow.	P.
1847. Jan. 29.	·077	178 13	7·36	19	5·7	8·796	5·8	5—5	Yellow.	P.
31.	·082	178 15	9·86	10	5·8	8·750	5·9	5·6—5·6	Yellow.	P.
Aug. 3.	·586	179 19	11·04	8	5·6	8·736	5·8	5—5	Yellowish.	P.
19.	·630	178 36	8·14	15	6·1	8·700	6·2	5·6—5·6	Yellowish.	P.
32 **Eridani.**										
1843. Aug. 18.	·627	346 29	9·91	10	8	6·866	8	6·7—8	White.	G.
Sept. 4.	·674	345 24	7·10	20	6	6·784	6	6—7	White.	G.
7.	·682	345 56	7·58	18	7	6·981	7	6·7—8	White.	G.
1845. Feb. *7.	·101	351 51	9·28	12	2·9	6·677	3·2	6·7—8	Yellow and blue.	P.
16.	·126	350 42	10·85	9	7	6·898	6·8	6·7—8·9	Red.	P.
17.	·129	349 41	11·72	7	6·8	6·758	6·6	6·7—8·9	Orange.	P.
1846. Feb. 10.	·110	348 23	8·44	14	4·1	6·664	4·2	7—9	White and bluish.	P.
1847. Jan. 31.	·082	347 12	6·60	23	4·8	6·642	5	7—9	Yellow and blue.	P.
1849. Feb. 17.	·129	346 39	11·97	7	2·2	6·714	2·1	6—8	Yellow and bluish.	P.
ω **Aurigæ.**										
1843. Sept. 8.	·684	349 28	11·46	8	7·4	6·588	7·4	7·8—9·10	White.	G.
16.	·706	350 20	14·38	5	7	6·367	7	7·8—9·10	White.	G.
24.	·728	351 19	10·55	9	7	6·343	7	8—10	White.	G.
1844. Sept. 25.	·734	351 37	12·30	7	6·6	6·724	6·7	7·8—10	Yellowish and light blue.	P.
26.	·736	351 6	13·43	6	6·9	6·546	6·6	7·8—10	Yellowish and light blue.	P.
Oct. 10.	·775	351 19	14·92	5	5·5	6·539	5·6	7·8—10	Yellowish and light blue.	P.
1845. Sept. 22.	·723	351 4	11·93	7	5·7	6·229	5·8	7·8—10	Yellowish and light blue.	P.
30.	·745	351 59	23·20	2	3·5	6·384	3·1	7—10	Yellowish and light blue.	P.
1846. Mar. 7.	·178	350 37	9·35	11	4·8	6·457	4·8	7·8—10	Yellow and whitish.	P.
12.	·192	351 37	14·81	5	5·8	6·442	5·9	7—10	Yellow and white.	P.
13.	·194	349 51	13·15	6	4·8	6·292	4·9	7—9·10	Yellow and blue.	P.
1847. Mar. 12.	·192	351 10	12·52	6	5·6	6·250	5·5	8—9·10	White and pale blue.	P.
24.	·225	351 35	20·59	2	2·2	6·297	2·1	7·8—9·10	Pale yellow and pale blue.	P.

* A power of 190 used.

TABLE I. (Continued.)

Year, Month and Day.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	Colours.	Observer.
1848. Mar. 31.	·246	351° 47′	11′·05	8	5	6″·233	5	6·7—9	Yellow and pale yellow.	P.
Apr. 1.	·249	352 8	10·61	9	5·8	6·230	5·4	6·7—8·9	Yellow.	P.
1849. Mar. 17.	·205	351 14	12·01	7	5·4	6·260	5·5	7·8—9·10	Yellow and white.	P.
						118 Tauri.				
1843. Sept. 24.	·728	196 46	11·31	8	7	4·866	7	8—9	White.	G.
27.	·736	196 36	5·48	33	7	4·612	7	8—9	White.	G.
1844. Mar. 10.	·189	195 20	5·53	33	3·6	5·065	3·4	8—9·10	White.	S.
29.	·241	195 22	8·57	14	5·8	4·967	5·6	8—9·10	Reddish.	S.
31.	·246	196 40	8·73	13	4	5·030	4	8—9·10	Reddish.	S.
Sept. 24.	·731	193 25	10·71	9	5·4	5·129	5·1	8—9	Light blue and bluish.	P.
25.	·734	195 9	8·93	13	7	5·087	7	8—9·10	Light blue and bluish.	P.
29.	·745	195 54	13·20	6	2·2	5·232	2·2	8—9·10	Light blue and bluish.	P.
1845. Feb. 26.	·153	192 1	25·48	2	5·8	4·796	5·5	7·8—9	Yellow and blue.	P.
Mar. 7.	·178	193 30	8·86	13	5·5	4·939	5·7	7·8—9	Light blue.	P.
8.	·181	194 8	15·76	4	3·3	4·984	3·3	7—9	Yellow and light blue.	P.
*13.	·194	191 17	43·84	1	1·4	5·033	1·3	7—9	Blue.	P.
20.	·214	196 49	17·13	3	5	5·097	4·8	7—9	Blue.	P.
Sept. 22.	·723	193 23	13·62	5	6·2	4·835	6·4	7—9	Yellow and light blue.	P.
1846. Feb. 28.	·159	196 7	10·35	9	3·9	5·035	3·6	7—8·9	Bluish and blue.	P.
Mar. 7.	·178	195 11	7·59	17	5·5	5·034	5·7	7—8·9	Bluish and white.	P.
						41 Aurigæ.				
1843. Feb. †15.	·123	351 25	16·19	4	4·6	7·856	3·6	7—8	White.	W. and G.
Mar. 1.	·162	352 2	24·41	2	4·2	8·393	4·5	7—8	White.	W. and G.
17.	·205	355 0	9·35	11	7	8·445	7	7·8—8	White.	G.
Sept. 1.	·665	352 0	14·44	5	5·9	7·857	5·9	8—9	White and rather blue.	W. and G.
8.	·684	354 18	4·66	46	7·8	7·930	7·8	8—9	White.	G.
16.	·706	353 9	10·20	10	6·8	7·820	6·8	8—9	White.	G.
1845. Feb. 26.	·153	352 41	11·46	8	5	8·097	5·2	8—9	White.	P.
Mar. 7.	·178	352 22	19·92	3	5·2	7·836	5	8—9	White.	P.
12.	·192	351 57	9·54	11	2·2	8·262	2·3	7·8—8·9	Blue.	P.
17.	·205	351 23	9·20	12	5·8	7·681	5·7	8—9	White.	P.
20.	·214	351 20	14·94	5	6	7·849	6·1	7·8—9	Yellowish.	P.
1846. Feb. 28.	·159	351 34	10·90	8	5·6	7·816	5·7	7·8—9	White and blue.	P.
Mar. 7.	·178	352 3	9·40	11	6	7·949	6·2	7·8—8·9	Whitish.	P.
1847. Mar. 10.	·186	352 42	9·79	10	4·6	7·925	4·4	7·8—9	Pale yellow.	P.
12.	·192	353 11	8·71	13	6·9	7·851	7	7·8—8·9	Pale blue.	P.
1848. Mar. 31.	·246	353 8	4·91	42	5·8	7·843	5·8	7·8—8·9	White.	P.
Apr. 1.	·249	353 18	7·71	17	5·9	7·876	6	7·8—8	White.	P.

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* A power of 320 used.

† *Ibid.*

Table I. (Continued.)

Year, Month and Day.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	Colours.	Observer.
δ Geminorum.										
1843. Apr. 5.	·257	194° 29′	10′·57	9	5·8	7″·610	5·8	3—10	White.	G.
10.	·271	195 34	79·59	0·2	0·4	8·400	0·4	3—10	White.	G.
11.	·274	194 12	9·07	12	5·2	7·614	4·9	3—9	White.	G.
1844. Mar. 29.	·241	197 58	12·35	7	5·5	7·310	5·7	3·4—11	Red.	S.
Apr. 1.	·249	198 5	13·45	6	5·2	7·468	5·5	3·4—11	Red.	S.
25.	·315	198 30	7·89	16	4·6	7·344	4·6	3·4—11	Red.	S.
1845. Oct. 31.	·830	197 54	17·95	3	5·8	7·295	5·6	3—11	Yellow and white.	P.
Nov. 12.	·862	198 30	9·14	12	5·8	7·322	5·8	3—11	Orange and light blue.	P.
1846. Apr. 9.	·268	198 42	9·19	12	5·8	7·355	5·8	3·4—10·11	Yellow and white.	P.
Anon. Cancri.										
1843. Mar. 18.	·208	353 14	24·99	2	8·6	3·802	8·5	8—8·9	White.	W. and G.
29.	·238	354 33	5·25	36	3·6	4·580	3·6	8—8·9	White.	G.
Apr. 11.	·274	352 59	9·65	11	5·8	4·015	6·9	7—7·8	White.	G.
1844. Apr. 1.	·249	351 25	8·40	14	6·6	3·557	6·6	8·9—9·10	White.	S.
May 1.	·331	352 24	11·06	8	3	3·599	3	8·9—10	White.	S.
2.	·334	352 10	19·26	3	1·8	3·598	1·8	8·9—10	White.	S.
1845. Apr. 3.	·252	354 3	10·23	10	6	3·498	6	8·9—10	White.	P.
8.	·266	353 11	19·53	3	5·6	3·361	5·7	8·9—10	White.	P.
20.	·298	353 10	8·47	14	5	3·314	5·3	8·9—10	White.	P.
Oct. 31.	·830	351 29	11·94	7	5·9	3·563	5·7	7·8—9·10	Light blue.	P.
Nov. 12.	·862	352 5	15·23	4	6	3·617	6·1	7·8—9·10	Light blue.	P.
1848. Apr. 3.	·255	353 42	9·58	11	5·8	3·479	5·7	8—9	Deep yellow and pale yellow.	P.
ϕ^2 Cancri.										
1843. Mar. 24.	·225	30 59	13·26	6	6·2	4·946	6	7—7	White.	G.
28.	·235	31 10	10·52	9	4	5·074	3·2	7—7	White.	G.
Apr. 20.	·298	31 54	7·44	18	6	4·930	6	5·6—5·6	White.	G.
1844. May 2.	·334	33 3	10·75	9	4·2	4·835	4·2	6·7—6·7	Reddish.	S.
5.	·342	32 52	8·56	14	4·3	4·889	4	6·7—6·7	Reddish.	S.
13.	·364	33 16	5·40	34	5	5·062	4·8	6·7—6·7	White.	S.
1845. Mar. 20.	·214	30 49	19·04	3	6	5·011	6	7—7	Yellow.	P.
24.	·225	32 15	11·54	8	6·2	4·696	5·8	7—7	Yellow.	P.
Apr. 2.	·249	33 2	11·21	8	4·8	4·779	4·1	7—7	Yellow.	P.
3.	·252	33 4	11·88	7	6·4	4·642	6·6	7—7	Yellow.	P.
Nov. 12.	·862	34 47	16·35	4	5·1	4·632	4·5	7—7	Light blue.	P.
22.	·890	33 4	11·43	8	7	4·701	6·8	7—7	Light blue.	P.
1846. Mar. 27.	·233	30 46	16·79	4	4	4·763	4	7—7	Bluish.	P.
Apr. 9.	·268	32 34	11·38	8	5	4·680	4·9	7—7	Bluish.	P.

Table I. (Continued.)

Year, Month and Day.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	Colours.	Observer.
					2 Comæ Berenices.					
1843. May 2.	·331	235° 15′	′38·45	1	0·6	″3·939	0·6	6·7—8·9	White.	G.
3.	·334	237 16	14·52	5	5	4·056	5	6·7—8·9	Yellowish and white.	G.
5.	·339	238 47	19·61	3	4	3·947	4	6·7—9	White.	G.
10.	·353	237 8	14·97	5	4	3·777	4	6·7—9	White.	G.
1844. May 13.	·364	243 58	6·72	22	4·6	4·092	3·8	6·7—9	Red.	S.
23.	·392	243 31	14·43	5	4	4·129	4	6·7—8·9	Reddish.	S.
June 10.	·441	237 2	6·56	23	6·4	4·145	6	6·7—8·9	Orange.	S.
Nov. 20.	·887	237 23	10·20	10	3·6	4·043	3·6	7—9	Yellowish blue and blue.	P.
1845. May 5.	·339	238 46	19·60	3	4·2	3·990	4·2	6·7—10	Yellow and light blue.	P.
13.	·361	236 55	20·89	2	5·7	4·052	5·4	6·7—9·10	Yellow and bluish.	P.
19.	·378	236 38	17·58	3	5·8	4·066	5·7	6·7—9·10	Yellow.	P.
Nov. 22.	·890	240 25	9·44	11	4·9	3·817	4·8	7—9	White and yellowish.	P.
1846. May 7.	·345	236 20	13·73	5	1·5	3·829	1·5	7—9	White.	P.
May 8.	·348	236 42	22·49	2	4·6	3·809	4·5	7—9	White.	P.
11.	·356	236 41	12·32	7	5·9	3·795	5·6	7—9	Orange and pale blue.	P.
1847. May 26.	·397	238 10	13·91	5	5·4	3·618	5·2	6·7—8	Pale yellow and blue.	P.
1848. May 3.	·337	239 51	11·68	7	5·7	3·709	5·2	6·7—8	White and pale blue.	P.
5.	·342	239 20	17·40	3	1·7	3·868	1·5	6·7—8·9	Yellow and pale blue.	P.
12.	·361	238 28	5·60	32	4·4	3·618	3·5	6·7—8·9	Yellow and pale blue.	P.
						39 Bootis *.				
1843. Mar. *2.	·164	41 11	……	…	0·9	3·993	0·9	7—7·8	White.	W. and G.
†4.	·170	43 1	……	…	2	4·080	2	8—8·9	White.	W. and G.
6.	·175	43 18	……	…	7·6	3·951	7·8	8—8·9	White.	G.
Aug. 18.	·627	43 25	……	…	6	3·764	6	6—6·7	White.	G.
19.	·630	44 1	……	…	7	3·922	7	6—6·7	White.	G.
Sept. 4.	·674	44 3	……	…	7	3·854	7	6—7	White.	G.
						δ Serpentis *.				
1843. Aug. 1.	·580	196 8	……	…	8	3·137	8	4—5	Yellowish.	G.
7.	·597	195 37	……	…	7	3·003	7	3—4	White.	G.
10.	·605	195 1	……	…	5	2·950	5	3—4	White.	G.
1844. July 26.	·567	197 15	……	…	1·5	3·146	1·7	3—5	Yellowish and light blue.	P.
Aug. 4.	·591	192 13	……	…	4	3·718	4	3—5	Yellowish and light blue.	W. and P.
9.	·605	192 58	……	…	1·6	3·133	1·6	3—5	Yellowish and light blue.	P.
28.	·657	197 34	……	…	5	3·310	5	3—5	Yellowish and light blue.	P.
29.	·660	197 16	……	…	5	3·151	5	3—5	Yellowish and yellowish blue.	P.
1845. Feb. 13.	·118	192 18	……	…	5·4	3·185	5·2	3—5	Yellow.	P.
17.	·129	190 47	……	…	7·6	3·135	7·6	3—5	Yellow and yellowish.	P.
17.	·129	192 26	……	…	6·8	3·105	6·3	3—5	Yellow and yellowish.	P.

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* A power of 320 used.

† *Ibid.*

Table I. (Continued.)

Year, Month and Day.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	Colours.	Observer.
		° ′	′			″				
1845. Aug. 7.	·597	194 40	......	...	5·4	3·105	5·2	4·5—6	Yellow.	P.
16.	·621	194 53	......	...	5·4	2·910	5·6	4—5·6	Yellow.	P.
Aug. 28.	·654	195 20	......	...	6·6	2·990	6·6	4—6	Yellow and light blue.	P.
1846. July 25.	·561	194 35	......	...	4·9	2·829	4·6	3·4—5·6	Yellow and light blue.	P.
30.	·575	195 4	......	...	1·5	2·970	1·4	3·4—5	Yellow and pale blue.	P.
Aug. 5.	·591	194 19	......	...	4·9	2·764	4·7	3·4—5	Yellow and pale blue.	P.
1847. Mar. 10.	·186	192 41	......	...	6	2·903	5·4	3·4—5·6	Yellow and yellowish.	P.
July 29.	·572	193 32	......	...	4·9	3·021	4·4	3·4—6	Orange and pale yellow.	P.
30.	·575	193 3	......	...	4·6	2·974	4·2	3·4—5·6	Orange and yellow.	P.
Aug. 1.	·580	193 35	......	...	6·2	2·805	6·3	3·4—6	Orange and yellow.	P.
1848. Aug. 19.	·632	195 9	......	...	0·8	2·847	0·7	4·5—6·7	Yellow and pale yellow.	P.
30.	·663	196 3	......	...	4·3	2·908	4·3	4—6	Yellow.	P.
Sept. 4.	·676	195 11	......	...	4·9	2·986	4·7	4—6	Yellow and pale yellow.	P.
178 **(Bode) Libræ.**										
1843. Aug. 1.	·580	7 39	7·92	16	7	12·374	7	8—8	White.	G.
7.	·597	6 49	11·65	7	5·4	11·798	5·4	8—8	White.	G.
11.	·608	8 14	8·47	14	5	12·195	5	8—8	White.	G.
1845. Feb. 14.	·120	7 15	15·12	4	3	12·232	3	8—8	Yellow and white.	P.
1847. Aug. *2.	·583	7 39	5·25	36	4·2	11·706	4·6	7·8—7·8	White.	P.
3.	·586	7 15	7·55	18	5·1	11·844	4·6	7·8—7·8	White.	P.
μ **Draconis** *.										
1843. Mar. †8.	·181	15 0	......	...	0·8	2·844	0·9	7—7·8	Bluish.	W.
17.	·205	17 12	......	...	4·3	3·693	4·3	8—8	White.	G.
24.	·225	17 27	......	...	5·7	3·402	5·3	7—7·8	Bluish.	W. and G.
Aug. 22.	·638	17 47	......	...	6	3·793	6	8—8	White.	G.
26.	·649	16 36	......	...	6	3·233	6	8—8	White.	G.
26.	·649	15 19	......	...	6·1	3·271	6·1	7·8—7·8	Bluish.	W.
1844. Aug. 28.	·657	17 46	......	...	4	3·241	4	7·8—7·8	Light blue.	P.
30.	·663	16 40	......	...	5	3·238	5	7—7	Light blue.	P.
31.	·665	17 5	......	...	5	3·285	5	7—7	Light blue.	P.
Sept. 2.	·671	17 16	......	...	4·2	3·110	4·2	7—7	Light blue.	P.
1845. Aug. 24.	·643	13 16	......	...	6·1	3·202	6·1	7—7	Bluish.	P.
27.	·652	12 27	......	...	6·8	3·209	6·4	7—7	Bluish.	P.
28.	·654	12 58	......	...	7	3·199	6·9	6·7—6·7	Bluish.	P.
1846. Mar. 9.	·183	13 16	......	...	6·9	3 074	6·8	7—7	Blue.	P.
20.	·214	12 29	......	...	5·3	3·063	4·8	7—7	Blue.	P.
Sept. 1.	·665	11 36	......	...	1·8	2·943	1·7	6·7—6·7	Pale yellow.	P.
2.	·668	11 35	......	...	6·5	2·996	6·3	6·7—6·7	Yellow.	P.
4.	·674	11 52	......	...	6	3·007	5·9	6·7—6·7	Yellow.	P.
1849. Sept. 5.	·676	10 0	......	...	5·2	2·980	5·3	6—6	Yellow.	P.
8.	·684	9 24	......	...	4·6	3·023	4·2	6·7—6·7	Pale yellow.	P.

* A power of 190 used.

† The powers of 320 and 450 used.

TABLE I. (Continued.)

Year, Month and Day.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	Colours.	Observer.
		° ′	′			″				
					100 Herculis.					
1843. Mar. 28.	·235	1 25	10·02	10	6	13·855	6	6·7—7	Bluish.	G.
Apr.* 13.	·279	0 50	18·24	3	4·5	14·471	4·2	5—5·6	Bluish.	W. and G.
18.	·293	2 6	10·87	9	5	14·508	5	6—6	Bluish.	G.
Aug.† 22.	·638	2 52	6·02	28	8	14·276	8	6—6	White.	G.
24.	·643	2 20	2·77	130	8	13·951	8	6—6	White.	G.
30.	·660	2 34	6·62	23	7	14·057	7	7—7	White.	G.
1844. Aug. 30.	·663	2 12	10·24	10	5	13·916	5	6—6	Light blue.	P.
Sept. 7.	·684	2 41	6·33	25	5·7	13·941	5·7	6—6	Bluish.	P.
10.	·693	2 38	4·44	51	5·9	14·031	5·9	6—6	Bluish.	P.
1845. Mar. 11.	·189	1 34	10·94	8	5·3	13·986	5·1	6—6	Blue.	P.
17.	·205	1 44	11·08	8	6	14·031	6	6·7—6·7	Bluish.	P.
19.	·211	1 41	13·06	6	6·3	13·858	6·3	6·7—6·7	Yellowish blue.	P.
Aug. 24.	·643	2 11	3·80	69	7	13·772	6·7	6·7—6·7	Blue.	P.
27.	·652	1 54	3·26	94	6	14·022	6	6·7—6·7	Bluish.	P.
28.	·654	2 1	4·61	47	7	13·900	6·9	6—6	Yellow.	P.
29.	·657	2 18	3·63	76	6	14·015	6	6—6	Yellow.	P.
1846. Aug. 29.	·657	2 32	6·24	26	2·3	13·944	2·4	6·7—6·7	Pale yellow.	P.
Sept. 2.	·668	2 9	6·51	24	6·1	13·893	5·8	7—7	Pale yellow.	P.
4.	·674	2 9	7·13	20	5·6	13·970	5·9	7—7	Pale yellow.	P.
1847. Mar. 18.	·208	2 45	4·73	45	5·1	13·989	5·2	6·7—6·7	Bluish.	P.
28.	·235	2 57	8·09	15	4·2	13·977	4·3	6·7—6·7	Pale yellow.	P.
Sept. 8.	·684	2 45	5·49	33	6·8	13·993	6·5	6·7—6·7	Pale yellow.	P.
27.	·736	2 10	6·00	28	6·6	13·941	6·5	6·7—6·7	Pale yellow.	P.
1848. Sept. 4.	·676	2 30	4·99	40	5·5	13·826	5·7	6·7—6·7	Yellow.	P.
16.	·709	2 25	4·61	47	6·7	13·993	6·6	6·7—6·7	Yellow.	P.
1849. Sept. 8.	·684	1 4	4·52	49	5·3	14·083	5·6	7—7	Yellow.	P.
Oct. 9.	·769	1 41	5·22	37	5·2	14·057	5·3	6·7—6·7	Yellow.	P.
					579 Struve.					
1843. Sept. 9.	·687	159 56	6·83	22	7	5·249	7	9—9	White.	G.
16.	·706	159 29	12·44	7	7	5·056	7	9—9	White.	G.
20.	·717	159 25	11·14	8	6	4·850	6	9—9	White.	G.
1844. Oct. 5.	·761	160 8	12·41	7	5·1	5·441	4·9	8—8	Bluish.	P.
7.	·767	159 28	26·85	1	3·4	5·240	3·6	8·9—8·9	Light blue.	P.
10.	·775	160 8	10·14	10	5·7	5·332	5·5	8·9—8·9	Bluish.	P.
15.	·789	159 36	14·68	5	5·9	5·299	5·6	8·9—8·9	Light blue.	P.
1845. Apr. 6.	·260	159 2	20·31	2	6·2	5·188	6	8·9—8·9	Light blue.	P.
Oct. 5.	·758	158 4	14·47	5	5·5	4·981	5·5	8·9—8·9	Bluish.	P.
11.	·775	158 44	21·23	2	5·5	5·092	5·2	8·9—8·9	Bluish.	P.
13.	·780	158 37	10·08	10	5·2	5·111	5·4	8·9—8·9	Bluish.	P.
1847. Oct. 7.	·764	159 22	13·02	6	4·5	4·875	5	8—8	White.	P.
12.	·778	159 20	16·32	4	3·3	4·976	3·1	8—8	Pale blue.	P.

* A power of 140 used.

† A power of 320 used.

Table I. (Continued.)

Year, Month and Day.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	Colours.	Observer.
						287 h and S.				
1844. Oct. 5.	·761	289° 28′	19′·90	3	0·8	7″·775	0·8	7·8—9	Light blue.	P.
15.	·789	291 22	13·60	5	3·4	8·486	3·4	7·8—9	Blue and light blue.	P.
18.	·797	291 2	6·63	23	4·3	8·205	4	7·8—9	Blue and bluish.	P.
23.	·810	291 17	4·72	45	0·8	8·557	0·9	7·8—9	Blue and bluish.	P.
1845. Apr. 6.	·260	290 54	8·44	14	3·5	8·486	3·4	7·8—8·9	Bluish.	P.
Oct. 5.	·758	291 57	18·50	3	4·8	8·080	4·6	7·8—9	Whitish and bluish.	P.
11.	·775	291 37	15·61	4	4·8	8·076	4·9	7·8—9	Whitish and bluish.	P.
16.	·789	290 31	12·92	6	4·2	7·949	4	7·8—8·9	Whitish and bluish.	P.
						ε Draconis.				
1843. Apr. 18.	·293	357 5	24·33	2	4	3·212	5	5—10	Yellowish and bluish.	G.
19.	·296	354 19	43·84	1	3·4	2·986	3·4	4—10	Bluish and white.	W. and G.
28.	·320	355 34	43·64	1	4·2	3·060	4	4—9	White.	W. and G.
1845. Oct. 24.	·810	354 40	38·58	1	1·8	2·802	1·7	5·6—10·11	Yellow and white.	P.
25.	·813	355 18	30·57	1	5·2	2·938	5·4	5—10	Yellow and white.	P.
31.	·830	357 28	16·91	4	5·8	2·982	6·2	5—9·10	Yellow and white.	P.
Nov. 1.	·832	356 9	9·02	12	6	2·972	6	5—9·10	Yellow and white.	P.
						I of H 95.				
1843. May 22.	·386	336 24	26·29	1	1·2	3·380	1·2	6·7—10	White.	G.
24.	·392	338 21	15·83	4	4	3·334	4	6·7—10	White.	G.
25.	·394	336 54	14·29	5	5	3·075	5	6·7—10	White.	G.
June 5.	·424	336 33	28·04	1	4·5	3·002	4·5	6·7—10	White.	G.
Nov. 23.	·893	344 42	44·69	1	1·5	3·523	1·5	6—8	White.	W. and S.
29.	·909	341 24	9·19	12	2·5	3·480	2·4	6—8	White.	S.
Dec. 24.	·977	342 29	25·38	2	3·8	3·149	3·2	6—8	White.	S.
1844. Jan. 2.	·003	344 3	21·48	2	1·2	3·677	1·1	6—8	White.	S.
7.	·016	342 24	12·01	7	5·5	3·115	5·3	6—8·9	White.	S.
June 1.	·416	341 43	9·27	12	5	3·252	4	6—8·9	Orange and white.	S.
3.	·422	341 26	14·52	5	1·4	3·294	1·3	6·7—9	Orange and white.	S.
10.	·441	341 44	17·58	3	4·7	3·286	4·4	6·7—9	Orange and white.	S.
July 29.	·575	339 26	10·39	9	3·2	3·085	3·2	6·7—9	Bluish white.	P.
Aug. 4.	·591	338 12	12·65	6	4·2	3·065	4·2	6·7—9	Bluish white.	P.
14.	·619	341 42	12·49	6	4·4	3·230	4	6·7—9	Bluish and light blue.	P.
24.	·646	341 27	24·86	2	2·4	3·113	2·4	6·7—9	Bluish white.	P.
Nov. 21.	·890	340 16	16·77	4	6·7	3·069	6·7	6·7—9	Bluish white.	P.
25.	·901	339 36	15·45	4	7	3·125	7·5	6·7—9	Bluish white.	P.
26.	·903	340 27	11·75	7	5·8	3·155	5·7	6·7—9	Bluish white.	P.
1845. Oct. 31.	·830	342 36	11·32	8	7	3·179	6·9	7—9	Light blue.	P.
Nov. 3.	·838	339 55	14·47	5	5·2	3·162	5·3	7—9	Bluish.	P.
4.	·841	342 26	22·19	2	4·3	3·163	4·2	7—9	Bluish.	P.
1846. May 10.	·353	342 23	10·17	10	4·8	3·115	4·9	7—9	Pale yellow and pale blue.	P.
29.	·405	342 12	13·47	6	6·7	3·010	6·6	7—9	Pale yellow and pale blue.	P.
Oct. 30.	·827	340 51	12·59	6	4·1	3·049	3·5	7—8·9	Pale yellow and pale blue.	P.

TABLE I. (Continued.)

Year, Month and Day.	Fraction of year.	Position.	Probable error,	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	Colours.	Observer.
						P XXII 306 *.				
1843. June 25.	·479	143 2	……	…	6	″8·467	6	6·7—9	White.	G.
July 3.	·501	143 56	……	…	6	8·353	6	6·7—9	White.	G.
6.	·509	144 17	……	…	5·5	8·461	5·5	6·7—9	White.	G.
Dec. 17.	·958	145 46	……	…	4·1	8·521	3·5	6·7—8·9	White.	S.
1844. Jan. 11.	·027	145 34	……	…	4·5	8·618	4·2	6·7—9	Reddish and white.	S.
13.	·033	144 13	……	…	4·9	8·788	4·7	6·7—9	White.	S.
Nov.* 27.	·906	146 0	……	…	6·4	8·670	6·5	7—9	Blue.	P.
1846. Dec. 14.	·950	146 18	……	…	1·1	8·350	1·3	8—10	Pale yellow and pale blue.	P.
22.	·972	146 3	……	…	4·1	8·335	3·8	7·8—9	Yellow and pale blue.	P.
1847. Dec. 28.	·988	146 16	……	…	1·7	8·024	1·7	7·8—9	Whitish and pale blue.	P.
1848. Dec. 21.	·972	145 37	……	…	4·6	8·251	4·7	7·8—9·10	Yellow and pale blue.	P.

The Second Table.—This table contains the means of all the results obtained at the same period of each year, when observations have been obtained on two or more days.

The *second column* contains the mean epoch of the results from which the means are formed.

The positions in the *third column* are computed in the ordinary mode by multiplying each individual set by its computed weight as contained in the fifth column of Table I., adding the products, and dividing by the sum of all the weights.

The *fifth column* contains the sum of the computed weights of the individual sets, from which the probable error of the mean in the preceding column is calculated from the equation

$$P=\frac{1}{\sqrt{W}}.$$

The computed weights inserted in the Tables have been multiplied by 1000.

The mean distances in the *seventh column* are computed in the same manner, using, however, the arbitrary or assigned weights in column 8 of Table I., instead of weights computed as above explained; for it was not deemed necessary, for reasons which will appear in the sequel, to apply the calculus of probabilities to the reduction of any of the observations of the distances.

The quantities in the *sixth and eighth* columns, headed "Assigned weight," are the sums of the weights assigned to the individual sets, from which each mean is formed.

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* A power of 190 used.

In the case of the four binary stars, to which an asterisk is attached in the Tables, the means, both of the positions and the distances, given in this table are obtained by employing the assigned or arbitrary weights, as before described.

In deference to the objections which may be urged to this mode of reduction, I had originally intended to use the common arithmetical mean in all these cases; but out of fifty-four means of positions computed strictly by the usual formulæ, and compared with means obtained as last described, and also with the arithmetical means of the same quantities, it was found that the mean obtained by using the arbitrary weights differed only in thirteen cases more than 9′ from the strict mean, and that in eight out of the thirteen cases, the result was rendered more erroneous by using the arithmetical mean, instead of the mean derived from the use of arbitrary weights: there were seven cases out of the fifty-four in which the computed and arbitrary weights gave precisely the same result.

Table II.

Name.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.
γ Arietis.	1843. ·576	179° 10′	7′·33	19	20	9″·078	20
	1844. ·069	179 42	7·54	18	9	8·957	9
	1845. ·083	180 38	5·92	29	15	8·816	15
	1847. ·080	178 14	5·89	29	12	8·773	12
	1847. ·608	178 51	6·55	23	12	8·717	12
32 **Eridani.**	1843. ·661	345 50	4·59	48	21	6·881	21
	1845. ·119	350 55	6·04	27	17	6·800	17
ω Aurigæ.	1843. ·706	350 26	6·84	21	21	6·436	21
	1844. ·748	351 22	7·76	17	19	6·607	19
	1845. ·734	351 16	10·60	9	9	6·283	9
	1846. ·188	350 37	6·77	22	15	6·400	16
	1847. ·209	351 17	10·66	9	8	6·263	8
	1848. ·248	351 58	7·65	17	11	6·231	10
118 **Tauri.**	1843. ·732	196 38	4·93	41	14	4·739	14
	1844. ·225	195 38	4·10	59	13	5·012	13
	1844. ·737	194 45	6·10	27	15	5·124	14
	1845. ·184	193 58	6·73	22	21	4·951	21
	1846. ·169	195 31	6·13	27	9	5·034	9
41 **Aurigæ.**	1843. ·163	353 54	7·69	17	16	8·290	15
	1843. ·685	353 56	4·07	60	21	7·873	21
	1845. ·188	351 52	5·17	37	24	7·899	24
	1846. ·169	351 51	7·13	20	12	7·885	12
	1847. ·189	352 58	6·51	24	12	7·880	11
	1848. ·248	353 11	4·14	58	12	7·860	12
δ Geminorum.	1843. ·267	194 24	6·62	23	11	7·640	11
	1844. ·268	198 18	5·96	28	15	7·375	16
	1845. ·846	198 23	8·14	15	12	7·309	11
Anon. Cancri.	1843. ·240	354 10	4·53	49	18	4·027	19
	1844. ·305	351 49	6·31	25	11	3·575	11
	1845. ·272	353 30	6·19	26	17	3·395	17
	1845. ·846	351 43	9·41	11	12	3·591	12
φ^2 Cancri.	1843. ·253	31 32	5·40	33	16	4·967	15
	1844. ·347	33 8	4·20	57	14	4·935	13
	1845. ·235	32 34	6·29	25	23	4·779	23
	1845. ·876	33 37	9·37	11	12	4·674	11
	1846. ·251	32 0	9·45	11	9	4·717	9
2 **Comæ Berenices.**	1843. ·339	237 25	8·94	13	14	3·937	14
	1844. ·399	240 42	4·46	50	15	4·126	14
	1845. ·359	237 24	11·11	8	16	4·040	15
	1846. ·350	236 33	8·48	14	12	3·805	12
	1848. ·347	238 46	4·85	43	12	3·701	10
39 **Bootis*.**	1843. ·170	43 4	……	……	11	3·979	11
	1843. ·644	43 51	……	……	20	3·851	20
δ Serpentis*.	1843. ·594	195 40	……	……	20	3·043	20
	1844. ·616	195 46	……	……	17	3·326	17
	1845. ·125	191 46	……	……	20	3·139	19
	1845. ·624	194 59	……	……	17	2·999	17
	1846. ·576	194 32	……	……	11	2·819	11
	1847. ·576	193 25	……	……	16	2·916	15
	1848. ·657	195 33	……	……	10	2·941	10

Table II. (Continued.)

Name.	Fraction of year.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.
178 (**Bode**) **Libræ.**	1843. ·595	7° 42′	5′·19	37	17	12″·144	17
	1847. ·585	7 31	4·31	54	9	11·775	9
μ **Draconis** *.	1843. ·204	17 2	......	......	11	3·521	11
	1843. ·645	16 34	......	......	18	3·431	18
	1844. ·664	17 10	......	......	18	3·222	18
	1845. ·650	12 53	......	......	20	3·203	19
	1846. ·199	12 56	......	......	12	3·069	12
	1846. ·669	11 42	......	......	14	2·994	14
	1849. ·680	9 43	......	......	10	2·999	10
100 **Herculis.**	1843. ·269	1 36	6·82	22	16	14·240	15
	1843. ·647	2 27	2·35	181	23	14·096	23
	1844. ·680	2 36	3·43	85	17	13·965	17
	1845. ·202	1 39	6·68	22	18	13·955	17
	1845. ·652	2 6	1·87	286	26	13·922	26
	1846. ·666	2 18	3·81	69	14	13·934	14
	1847. ·222	2 48	4·08	60	9	13·984	10
	1847. ·710	2 29	4·05	61	13	13·967	13
	1848. ·693	2 27	3·39	87	12	13·916	12
	1849. ·727	1 20	3·42	86	11	14·070	11
579 **Struve.**	1843. ·703	159 44	5·26	36	20	5·062	20
	1844. ·773	159 59	6·71	22	20	5·333	20
	1845. ·771	158 28	7·72	17	16	5·060	16
	1847. ·771	159 21	10·15	10	8	4·914	8
287 **h** and **s.**	1844. ·789	291 9	3·64	76	9	8·307	9
	1845. ·774	291 11	8·77	13	14	8·040	14
ε **Draconis.**	1843. ·303	356 17	19·25	3	12	3·101	12
	1845. ·821	356 18	7·54	18	19	2·951	19
I of H 95.	1843. ·399	337 18	9·29	12	15	3·148	15
	1843. ·960	342 6	6·58	23	15	3·279	14
	1844. ·530	340 40	4·82	43	25	3·187	24
	1844. ·898	340 10	8·17	15	20	3·115	20
	1845. ·836	341 42	8·25	15	17	3·169	16
	1846. ·379	342 19	8·11	15	12	3·055	12
P XXII 306 *	1843. ·496	143 44	......	......	18	8·420	18
	1844. ·006	145 8	......	......	14	8·655	12
	1846. ·961	146 6	......	......	5	8·339	5

The Third Table.—This Table contains the general means of all the observations of each star, both in position and distance, reduced to the mean epoch of all the observations, which will be found in *column three.*

The positions in *column four*, and the probable errors and weights in *columns five and six*, are obtained by combining the means and individual sets (where one set only has been obtained at any one period) in accordance with the theory of probabilities, as above mentioned, except in the case of the four binary stars, in which the arbitrary weights are substituted for computed ones, as before explained.

Where two stars are supposed to be of equal brightness, it has been usual to register always the smaller of the two angles, by which the position may be designated, according as the one or the other component be considered as the larger star.

In these cases there is some confusion as to the identity of the two stars, which might be obviated by astronomers agreeing always to designate the northern, or in cases of equal N.P.D., the east star as A.

The *seventh and ninth* columns contain the sums of the assigned or arbitrary weights.

The *eighth column* contains the mean of all the observed distances, obtained in all cases by using the arbitrary weights.

The *tenth column* contains the mean of all the registered magnitudes of each component star, the first No. referring to the brightest of the two components, or in cases of equal brightness, to the star called A.

The *eleventh and twelfth* columns contain the R.A. and N.P.D. of each star, taken from the B. A. C.; and when the star is not found in that Catalogue, from STRUVE's of 1837.

The *thirteenth column* contains the total number of individual measures in position; the number of measures in distance being equal in every case, except one, that is specified, one column suffices for both position and distance.

In the notes will be found notices of any remarkable differences between the measures contained in this Table, and those given by STRUVE in his Catalogue of 1837:—they are confined to differences exceeding 1° in position, and $0''\cdot200$ in distance.

TABLE III.

No.	Name.	Mean epoch.	Position.	Probable error.	Computed weight.	Assigned weight.	Distance.	Assigned weight.	Magnitudes.	R.A.	N.P.D.	*n*.
			° ′	′			″			h m	° ′	
1	γ Arietis[a]	1845. ·483	179 18	2·93	117	68	8·887	68	5·3— 5·3	1 45	71 27	118
2	32 Eridani	1846. ·220	347 37	2·90	119	49	6·803	49	6·5— 8·2	3 47	93 24	86
3	ω Aurigæ	1846. ·434	351 5	3·14	102	89	6·401	88	7·3— 9·7	4 49	52 21	154
4	118 Tauri[b]	1844. ·962	195 27	2·35	182	79	4·955	78	7·6— 9·1	5 20	64 59	150
5	41 Aurigæ	1845. ·607	353 5	2·15	216	95	7·947	95	7·6— 8·7	6 0	41 16	162[o]
6	δ Geminorum[c]	1844. ·912	197 14	3·58	78	44	7·422	44	3·2—10·5	7 11	67 45	82
7	Anon. Cancri[d]	1845. ·384	353 16	2·86	122	64	3·655	65	8·1— 9·3	7 56	62 3	113
8	φ² Cancri[e]	1844. ·992	32 36	2·70	137	74	4·823	71	6·8— 6·8	8 18	62 35	137
9	2 Comæ Berenices[f]	1845. ·746	239 4	2·60	148	82	3·916	78	6·6— 8·8	11 57	67 42	166
10	39 Bootis ✱[g]	1843. ·407	43 35	...	...	31	3·896	31	6·8— 7·4	14 45	40 40	46
11	δ Serpentis ✱[h]	1846. ·119	194 21	...	...	117	3·042	115	3·5— 5·3	15 28	78 57	215
12	178 (Bode) Libræ[i]	1845. ·433	7 34	3·24	95	30	12·038	30	7·8— 7·8	15 29	98 10	56
13	μ Draconis ✱[k]	1845. ·673	14 15	...	...	103	3·217	101	7·0— 7·1	17 2	35 20	184
14	100 Herculis	1846. ·247	2 14	1·02	959	158	14·005	158	6·4 — 6·4	18 2	63 55	260
15	579 Struve	1845. ·456	159 29	3·39	87	70	5·131	70	8·5— 8·5	18 31	48 49	124
16	287 h and s[l]	1845. ·274	291 7	3·12	103	27	8·192	26	7·5— 8·9	18 58	83 7	56
17	ε Draconis[m]	1844. ·562	356 18	7·02	20	30	3·010	32	4·8— 9·8	19 49	20 7	64
18	I of H 95	1845. ·118	340 53	2·78	129	106	3·157	103	6·5— 8·8	20 14	35 9	211
19	P XXII 306 ✱[n]	1846. ·055	144 56	...	...	49	8·475	48	7·0— 9·1	22 59	58 7	96

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[a] γ Arietis. Distance, $\Sigma-\mathrm{W}=-0''{\cdot}256$, period elapsed $=14{\cdot}64$ years.

[b] 118 Tauri. Position, $\Sigma-\mathrm{W}=+1^{\circ}\,20'$, period $=15{\cdot}33$ years.

[c] δ Geminorum. Distance, $\Sigma-\mathrm{W}=-0''{\cdot}277$, period $=15{\cdot}19$ years.

[d] Anon. Cancri. This star is erroneously termed 11 Cancri in HERSCHEL and SOUTH's Catalogue. See SMYTH's Cycle: it is 2688 B.A.C.

[e] φ² Cancri. Distance, $\Sigma-\mathrm{W}=-0''{\cdot}260$, period $=15{\cdot}54$ years.

[f] 2 Comæ Berenices. Position, $\Sigma-\mathrm{W}=+1^{\circ}\,33'$, period $=16{\cdot}21$ years.

[g] 39 Bootis. Comparing the place of this star in position with that given by HERSCHEL and SOUTH and by STRUVE, its mean yearly motion by

$\mathrm{Sh}-\mathrm{W}=-4'{\cdot}39$, period $=20{\cdot}48$ years.
$\Sigma-\mathrm{W}=-2'{\cdot}39$, period $=13{\cdot}39$ years.

Mean $=-3'{\cdot}39$

[h] δ Serpentis. Comparing the place of this star in position with that given by HERSCHEL and SOUTH and by STRUVE, its mean yearly motion by

$\mathrm{Sh}-\mathrm{W}=-12'{\cdot}18$, period $=24{\cdot}80$ years.
$\Sigma-\mathrm{W}=-13'{\cdot}49$, period $=13{\cdot}05$ years.

Mean $=-12'{\cdot}84$
Distance, $\Sigma-\mathrm{W}=-0''{\cdot}380$

[i] 178 (Bode) Libræ. Distance, $\Sigma-\mathrm{W}=-0''{\cdot}225$, period $=14{\cdot}89$ years.

[k] μ Draconis. The mean yearly motion of this star in position by

$\mathrm{Sh}-\mathrm{W}=-35'$, period $=24{\cdot}30$ years.
$\Sigma-\mathrm{W}=-49'$, period $=13{\cdot}45$ years.

Mean $=-42'$

[l] 287 h and s. Position, $\Sigma-\mathrm{W}=+1^{\circ}\,13'$, period $=15{\cdot}47$ years.

[m] ε Draconis. $\left.\begin{array}{l}\text{Position, } \Sigma-\mathrm{W}=-1^{\circ}\,46' \\ \text{Distance, } \Sigma-\mathrm{W}=-0''{\cdot}220\end{array}\right\}$, period $=12{\cdot}12$ years.

[n] P XXII 306. The mean yearly motion of this star in position by

$\mathrm{Sh}-\mathrm{W}=-9'{\cdot}10$, period $=22{\cdot}31$ years.
$\Sigma-\mathrm{W}=-4'{\cdot}78$, period $=15{\cdot}47$ years.

Mean $=-6'{\cdot}94$

[o] The measures of distance are one less in number than those of position in the case of this star.

The Fourth Table.—This Table has been formed for the purpose of exhibiting the results from which, in conformity with the principles explained by Sir John Herschel, the existence or non-existence of parallax in the stars observed must be inferred.

These results are the differences between two angles of position, the one observed at one period of the year, say the early one, and the other at another period (the late) distant from the former about six months.

For reasons which will appear hereafter, it has not been deemed necessary to include the distances in this table.

In so delicate an inquiry as that of parallax, it may not perhaps be considered a legitimate course to pursue, to compare any results except those distant from one another by an interval of about six months, or in other words, results which follow one another immediately at opposite seasons. It is on differences so obtained that many therefore may be disposed to rely exclusively in discussing the questions raised by this investigation; and such differences, when furnished by the observations, are accordingly placed first in the table; but it is in truth only a choice of difficulties; it has been found impossible in the case of some of the stars to obtain such differences at all; and in others, the observations are so few, and their weight consequently so small, at one at least of the periods compared, that little reliance can be placed on the results; it has been thought better therefore to combine in the case of each star, and in the manner already explained, all the observations made in all the years at the early period into one mean result, and all those made at the late period into another, and to insert their difference, leaving it to astronomers to attach whatever importance to the comparison they may think due to it. This difference follows in every case the more legitimate comparisons at intervals of six months.

The four binary stars are excluded from this Table.

The *second column* of this fourth Table contains the mean epoch:—in the case of the *final* means, that is, the means of all the *early* and all the *late* periods, the decimal, following an enumeration of several years, is the mean of all the decimals attached to the years of the individual means or sets, from which the final means are formed.

The *third column* contains the positions, obtained by using the computed weights of the results employed, as before explained.

The *fourth* and *fifth columns* contain the probable errors and weights of these positions.

The *sixth column* contains the differences between the positions, which follow one another in succession, and which have been obtained at opposite periods of the year; or, in other words, the quantity, on which parallax depends, and to which the subjoined remarks on the results of the observations refer.

The *plus* sign is attached to the difference when the change in the angle takes place in that direction, which is in conformity with the hypothesis of a parallax in the stars observed; and the *minus* sign when the change is in the contrary direction.

The *eighth column* contains the weight of the difference computed from the formula

$$W''=\frac{WW'}{W+W'},$$

where W and W′ are the weights of the two positions compared, and W″ the weight of their difference:—from the value of W″ so obtained, that of the probable error of the difference, inserted in the *seventh column*, is computed by the above equation.

The *ninth column* contains the distance, taken from the third Table to the first place of decimals.

All the computations have been very carefully examined.

TABLE IV.

Name.	Epoch.	Position.	Probable error.	Weight.	Difference.	Probable error of Δ.	Weight of Δ.	Distance.
		° ′	′		′	′		″
γ Arietis.	1843. ·576	179 10	7·33	19	− 32	10·52	9	8·9
	1844. ·069	179 42	7·54	18				
	1847. ·080	178 14	5·89	29	+ 37	8·81	13	
	1847. ·608	178 51	6·55	23				
	1843, 7. ·592	178 59	4·89	42	− 30	6·10	27	
	1844, 5, 7. ·077	179 29	3·65	75				
32 **Eridani.**	1843. ·661	345 50	4·59	48	+178	5·92	29	6·8
	1845, 6, 7, 9. ·110	348 48	3·74	72				
ω Aurigæ.	1845. ·734	351 16	10·60	9	− 39	12·58	6	6·4
	1846. ·188	350 37	6·77	22				
	1843, 4, 5. ·729	350 55	4·62	47	+ 18	6·30	25	
	1846, 7, 8, 9. ·213	351 13	4·28	55				
118 **Tauri.**	1843. ·732	196 38	4·93	41	+ 60	6·42	24	5·0
	1844. ·225	195 38	4·10	59	− 53	7·35	19	
	1844. ·737	194 45	6·10	27	+ 47	9·08	12	
	1845. ·184	193 58	6·73	22	− 35	15·18	4	
	1845. ·723	193 23	13·62	5	−128	14·93	5	
	1846. ·169	195 31	6·13	27				
	1843, 4, 5. ·731	195 42	3·69	73	+ 26	4·78	44	
	1844, 5, 6. ·193	195 16	3·04	108				
41 **Aurigæ.**	1843. ·163	353 54	7·69	17	− 2	8·22	15	7·9
	1843. ·685	353 56	4·07	60				
	1843, 5, 6, 7, 8. ·191	352 45	2·53	156	− 71	4·79	44	
	1843. ·685	353 56	4·07	60				
δ Geminorum.	1845. ·846	198 23	8·14	15	− 19	12·29	7	7·4
	1846. ·268	198 42	9·19	12				
	1843, 4, 6. ·268	196 58	3·99	63	+ 85	9·06	12	
	1845. ·846	198 23	8·14	15				
Anon. Cancri.	1845. ·272	353 30	6·19	26	+107	11·26	8	3·7
	1845. ·846	351 43	9·41	11				
	1843, 4, 5, 8. ·268	353 26	3·00	111	+103	9·88	10	
	1845. ·846	351 43	9·41	11				

TABLE IV. (Continued.)

Name.	Epoch.		Position.	Probable error.	Weight.	Difference.	Probable error of Δ.	Weight of Δ.	Distance.
			° ′	′		′	′		″
φ² **Cancri.**	1845.	·235	32 34	6·29	25	− 63	11·28	8	4·8
	1845.	·876	33 37	9·37	11	− 97	13·30	6	
	1846.	·251	32 0	9·45	11				
	1843, 4, 5.	·278	32 30	2·82	126	− 67	9·78	11	
	1845.	·876	33 37	9·37	11				
2 **Comæ Berenices.**	1844.	·399	240 42	4·46	50	−199	11·14	8	3·9
	1844.	·887	237 23	10·20	10	− 1	15·09	4	
	1845.	·359	237 24	11·11	8	+181	14·59	5	
	1845.	·890	240 25	9·44	11	+232	12·70	6	
	1846.	·350	236 33	8·48	14				
	1843, 4, 5, 6, 7, 8.	·365	239 4	2·80	127	− 3	7·48	18	
	1844, 5.	·889	239 1	6·93	21				
178 (**Bode**) **Libræ.**	1843, 7.	·590	7 35	3·32	91	+ 20	15·44	4	12·0
	1845.	·120	7 15	15·12	4				
100 **Herculis.**	1843.	·269	1 36	6·82	22	+ 51	7·21	19	14·0
	1843.	·647	2 27	2·35	181				
	1844.	·680	2 36	3·43	85	− 57	7·51	18	
	1845.	·202	1 39	6·68	22	+ 27	6·94	21	
	1845.	·652	2 6	1·87	286				
	1846.	·666	2 18	3·81	69	− 30	5·58	32	
	1847.	·222	2 48	4·08	60	− 19	5·75	30	
	1847.	·710	2 29	4·05	61				
	1843, 5, 7.	·231	2 18	3·10	104	− 4	3·28	93	
	1843, 4, 5, 6, 7, 8, 9.	·682	2 14	1·08	855				
579 **Struve.**	1844.	·773	159 59	6·71	22	− 57	21·49	2	5·1
	1845.	·260	159 2	20·31	2	+ 34	21·82	2	
	1845.	·771	158 28	7·72	17				
	1843, 4, 5, 7.	·755	159 30	3·43	85	− 28	20·70	2	
	1845.	·260	159 2	20·31	2				
287 **h** and **s.**	1844.	·789	291 9	3·64	76	+ 15	9·20	12	8·2
	1845.	·260	290 54	8·44	14	+ 17	12·18	7	
	1845.	·774	291 11	8·77	13				
	1844, 5.	·782	291 9	3·36	89	+ 15	9·10	12	
	1845.	·260	290 54	8·44	14				
ε **Draconis.**	1843.	·303	356 17	19·25	3	+ 1	20·67	2	3·0
	1845.	·821	356 18	7·54	18				
I of **H** 95.	1843.	·399	337 18	9·29	12	+288	11·38	8	3·2
	1843.	·960	342 6	6·58	23	+ 86	8·15	15	
	1844.	·530	340 40	4·82	43	− 30	9·48	11	
	1844.	·898	340 10	8·17	15				
	1845.	·836	341 42	8·25	15	− 37	11·57	8	
	1846.	·379	342 19	8·11	15	− 88	14·98	5	
	1846.	·827	340 51	12·59	6				
	1843, 4, 6.	·436	340 28	3·78	70	+ 55	5·59	32	
	1843, 4, 5, 6.	·880	341 23	4·11	59				

Results of the observations.

Distances.—In discussing the results of the observations, little need be said of the measures of distance: it was impracticable, consistently with the due prosecution of the more important task of measuring the angles, to take these measures of distance at shorter intervals, and at the epochs proper for eliminating the changes, if any, due to parallax: the small differences between the measures taken at opposite seasons must be ascribed to errors of observation.

The following Table exhibits these differences; it contains the means of the measures of distance obtained at the early and late periods, with the sums of the assigned weights used in the reduction, and which means correspond, in respect to epoch, with the *final* means of the angles contained in the fourth Table; the mean epochs themselves therefore have been already given in that Table.

The four binary stars are excluded from the following Table.

Table V.

Name.	Mean distance.	Assigned weight.	Δ.	Name.	Mean distance.	Assigned weight.	Δ.
	″				″		
γ Arietis	8·943	32	·105	2 Comæ Berenices ...	3·917	69·7	·003
	8·838	36			3·914	8·4	
32 Eridani	6·881	21	·136	178 (Bode) Libræ ...	12·016	26·6	·216
	6·745	27·9			12·232	3·0	
ω Aurigæ	6·474	49·2	·165	100 Herculis	14·064	42·1	·081
	6·309	39·1			13·983	115·5	
118 Tauri	4·915	34·7	·072	579 Σ	5·126	63·8	·062
	4·987	42·9			5·188	6·0	
41 Aurigæ	7·967	74·5	·094	287 h and s	8·148	22·6	·338
	7·873	20·5			8·486	3·4	
δ Geminorum	7·461	32·7	·152	ε Draconis..............	3·101	12·4	·150
	7·309	11·4			2·951	19·3	
Anon. Cancri	3·669	53·1	·078	I of H 95	3·145	49·7	·023
	3·591	11·8			3·168	53·3	
φ^2 Cancri	4·851	59·6	·177				
	4·674	11·3					

Angles of position.—In the discussion of the measures of position, it must be remembered that four of the stars observed, viz. 39 Bootis, δ Serpentis, μ Draconis, and P XXII 306, exhibit differences in their mean positions, as compared with those given by other observers, of an amount sufficient to induce the belief that they are binary systems: the observations of these stars may therefore be at once dismissed with the remark, that they are useless for the purposes of this inquiry. Again, in the case of five other stars, viz. γ Arietis, φ^2 Cancri, 178 (Bode) Libræ, 100 Herculis and 579 Struve, the components are of equal magnitude, and parallax is in this case not only *à priori* highly improbable, but there is nothing in the actual observations themselves of these stars, which can lead us to any definite conclusion as to its existence in fact. It is proper, however, to direct attention to the large differences in the case of φ^2 Cancri, accordant in respect of sign.

In order to arrive at any decision on the question, whether the changes in the angles of position of the remaining stars, exhibited in the sixth column of the fourth

Table headed "Difference," should induce us to suspect the existence of a sensible parallax in any of the objects observed, two points are to be considered,—first, the *amount* of those changes, as compared with the probable error of the results themselves; and secondly, their *direction*, considered with reference to the motion of the earth in her orbit.

As to the first point, it would appear, that except the change observed bear a very large proportion to the probable error of the determination, it may be justly treated with little respect, so far as the evidence to be derived from *amount* only be concerned.

This conclusion is supported, first, by the great discordances between the partial differences, in the instances of the three stars, 118 Tauri, 100 Herculis, and I of H 95, the only objects that can be said to have been satisfactorily observed, if the delicate nature of the investigation be considered.

2ndly. These discordances are the more remarkable, when we view them in connection with the large ratios which some of the differences bear to their probable errors. Indeed a bare inspection of the measured angles of position given in Table I. in connexion with the computed weights and errors, will convince us that the differences of the results obtained on different evenings are greater in many instances than those of the separate measures obtained on the same evening. This circumstance, which, it is believed, is not unfrequent in observations requiring the same delicacy of estimation as those under consideration, renders the application of the calculus of probabilities embarrassing and its conclusions uncertain. It is certain, in fact, that in the greater number of instances given in this paper, the computed probable errors of the results on which the parallaxes depend, form no probable criterion of the magnitude or even of the existence of parallax. The only probable explanation that can be given in such cases, where purely instrumental errors can scarcely have place, must arise from an unsuspected bias of the observer in the selection of the line of direction passing through the centres of the stars, which causes an estimation constant on the same evening, but differing on different nights. The weight of each evening's result, calculated according to the amount of discordance of the individual measures, may still be an adequate representative of the degree of dependence to be placed on it, as far as the steadiness of the atmosphere and other favourable circumstances are concerned; but the probable errors of combined and final results, calculated on ordinary principles, will not form a good criterion of the accuracy of such results. Supposing, however, the bias of the observer on different evenings likely to be as often in excess as in defect, or not to be of the nature of a constant error, a better estimation of the probable error of the final means would be obtained by considering each evening's set of measures as a single result without regard to their number, and then comparing the separate results in the usual way*. If the results in the present paper had been of a more positive character, a re-reduction of some of them on this principle might have been desirable, but as the case stands this explanation is sufficient. It is proper to add, that I have no reason to believe, that a single *individual* measure, either in position or distance, however discordant, has been ever rejected on that or any other ground; but all *sets* containing less than four measures have been invariably rejected.

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* Putting p for the probable error of 10 *sets* of 118 Tauri for the early period, treated as *individual* measures, and p' for the mean of the probable errors, as given in Table I., of the same sets, $p : p' :: 24 : 15$. In the case of 10 sets of I of H 95 for the late period, $p : p' :: 11 : 9$.

It would seem, then, that though, in one point of view, comparisons at opposite seasons must be treated as possessing value, yet we are after all driven to rely in a great measure on the final means; for notwithstanding the well-founded objections that may be urged to combining observations made in different years, the discordances above alluded to show, that a greater number of measures are required to eliminate error, than can possibly be obtained in any one, or even two years.

Now if we examine the final means of the two periods in Table IV., we shall find five stars only, viz. 32 Eridani, 41 Aurigæ, δ Geminorum, Anon. Cancri, and I of H 95, of which we can affirm that they have any pretensions whatever to be considered as fulfilling the condition above stated:—with respect to δ Geminorum and Anon. Cancri, the small weights of the results of the late period render any conclusions drawn from them extremely liable to doubt: this is the more to be regretted, in the case of the last-mentioned star, inasmuch as the smallness of the distance of its components renders it a very eligible object for observation.

When however we examine the results obtained with reference to the *direction* of the changes observed, they seem to be entitled to rather more consideration.

In the *nf* and *np* quadrants an apparent motion to the westward of the larger star, assumed to be the nearest to the earth, must increase the angle of position, and in the *sf* and *sp* quadrants the contrary effect must take place:—therefore at that epoch of observation when the sun is to the west, and therefore the earth to the east, of the star observed, the *maximum* angle may be expected to occur in the two first named quadrants, and the *minimum* in the others; in the case of double stars, whose components are equal, it is plain that two different conclusions may be drawn from the periods at which the maxima occur, according as the one or the other be taken as the nearest star.

Omitting therefore the five stars, whose components are of equal magnitude, omitting also the four binary stars, and 2 Comæ Berenices and ε Draconis (which exhibit differences less than their probable errors), this interesting result appears, that of the eight that remain, there is only one, that is, 41 Aurigæ, the changes in whose angles, however small and little entitled to confidence they may be, do not conform in direction to those, which would take place, were a sensible parallax admitted in the brighter of the stars themselves.

This is most probably only an accidental coincidence, and I am very far from wishing to estimate it at more than its real worth; but in the case of 32 Eridani and I of H 95, where large, and to a certain extent trustworthy, differences concur with normal directions of motion, it may not perhaps be too much to assert, that this constitutes them objects of interest to the astronomer, possessed of adequate means to prosecute an inquiry, which, I fear, I must be said rather to have attempted than to have succeeded in.

Wrottesley, October 22, 1850.

XIV. *Researches into the Molecular Constitution of the Organic Bases.*

By Dr. A. W. HOFMANN, *F.C.S., Professor of the Royal College of Chemistry of London.*

(Second Memoir.) Communicated by Sir JAMES CLARK, *Bart., F.R.S.*

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ABOUT twelve months ago I had the honour of presenting to the Royal Society an account of a series of researches into the molecular constitution of the *volatile* organic bases[*]: at present I beg to submit to the consideration of the Society the history of a new group of alkaloids, which, although intimately connected with the former by their origin, differ from them altogether by their properties, and especially in *not being volatile.*

The members of this new group of alkaloids are so numerous, their deportment is so singular, and their derivatives ramify in so many directions, that I have not as yet been able to complete the study of these substances in all their bearings; nor is it my intention to go fully into the chemistry of the subject in the present communication, my object being merely to establish the existence of these bodies, and to give a general outline of their connection with the *volatile* bases, and of their most prominent chemical and physical properties, reserving a detailed description of their salts and derivatives to a future memoir.

In the paper above referred to, I advanced the position that the majority of the volatile organic bases might be represented by the general expression

$$\left.\begin{array}{c}X\\Y\\Z\end{array}\right\}N,$$

a formula which coincides with that of ammonia, if $X=Y=Z=H$. I proved by experiment that the terms X, Y and Z may represent, not only hydrogen, but a variety of hydrocarbons, especially the so-called alcohol-radicals $(C_n\,H_{(n+1)})$, and endeavoured, on the ground of these experiments, to classify the volatile organic bases according to the amount of basic[†] hydrogen retained in the several alkaloids. I thus arrived at three groups of bases, for which, in accordance with traditional names, I proposed the terms amidogen-bases, imidogen-bases and nitrile-bases.

The ideas enunciated regarding the constitution of the volatile organic bases, were, it is true, to a certain extent, the result of theoretical speculation; but they were so

[*] Philosophical Transactions, Part I. 1850, p. 93.

[†] Ibid. p. 111.

perfectly in accordance with all the observations recorded, and had been submitted to the test of experiment in so many directions, that no doubt was left in my mind regarding their correctness. Still, the former inquiry had elicited several facts which I was unable to explain by the view which I had taken. These facts I have since endeavoured to elucidate by additional experiments; the results detailed in the following pages, I am happy to say, are in perfect accordance with my former observations, the extension of which has led me, at the same time, to a still more general conception of the question.

After having succeeded in replacing, step by step, one, two or three equivalents of hydrogen in ammonia by a corresponding number of compound atoms, the question arose whether the agent by which these changes were affected would exert a still farther influence upon the last product of the reaction. In order to decide this question by experiment, I submitted two nitrile-bases, diethylaniline and triethylamine, to a prolonged action of bromide of ethyl. These experiments, of which a full account is given in my preceding memoir (pages 106 and 122), did not lead to perfectly decisive results. It was evident that in these cases a reaction ensued; even on using both the base under examination, and the bromide in the absolutely dry state, a gradual change was observed to take place, a small but unmistakeable quantity of hydrobromates being invariably formed. No doubt, however, could be entertained as to this reaction being altogether different from the preceding stages of the process, for instance, the conversion of ammonia into ethylamine, of ethylamine to diethylamine, &c.; it was proved, moreover, by careful and frequently-repeated experiment, that this process, whatever its nature might be, in no case gave rise to the formation of any other *volatile* bases containing a larger number of replacing radicals than the nitrile-base submitted to investigation.

I have been again studying these reactions during the past year on a much larger scale, whereby the experiments were greatly facilitated; and here I gladly avail myself of an opportunity of expressing my sincere thanks to the Royal Society for the kind and encouraging interest they have taken in this inquiry, the new results of which are mainly attributable to their liberal and munificent support.

ACTION OF BROMIDE AND IODIDE OF ETHYL UPON TRIETHYLAMINE.

In the paper repeatedly referred to, I have stated that a mixture of an aqueous solution of triethylamine and bromide of ethyl, sealed up in a tube, solidified after several hours' ebullition, and that the crystals consisted chiefly of the fibrous hydrobromate of triethylamine, with which however a certain quantity of white opake granular crystals invariably was mixed. I have endeavoured to increase the quantity of the latter by using both the bromide of ethyl and the triethylamine in the anhydrous state. But by thus changing the conditions of the formation, the progress of the reaction is retarded in the most remarkable manner, days elapsing before the conversion is completed. While engaged in these experiments, I found that the result intended may be obtained almost instantaneously by substituting the iodide for the bromide of ethyl; and as this observation was immediately followed by a perfect elucidation of the whole question, I have scarcely returned again to the use of the bromide.

On adding perfectly anhydrous iodide of ethyl to triethylamine dried over hydrate of potassa, the mixture becomes slightly turbid, heat being evolved at the same time. At the common temperature the action goes on very gradually, and after the lapse of several days, the mixture is converted into a solid mass. On the other hand, if the mixture be exposed for a minute or two to the temperature of boiling water, a very powerful reaction ensues; the liquid remains, even after the removal of the source of heat, for some time in a state of lively ebullition, and solidifies after cooling, into a hard mass of crystals, which is snow-white or of a yellowish tint, according as either the triethylamine or the iodide of ethyl has been in excess. To avoid losing iodide of ethyl, and especially triethylamine, which is the result of a long series of troublesome and expensive processes, I have usually performed the reaction in strong glass tubes of between three and four feet in length, which were sealed before the blowpipe after the substances had been introduced.

The crystalline mass produced in this reaction readily dissolves even in cold water. If the iodide was in excess this substance separates in heavy oily globules, which may be readily separated and recovered by distillation, and the solution is inodorous, and either neutral or very slightly acid; in the latter case it has always a marked yellowish tint. On the other hand, if the base was in excess, the solution of the crystals was colourless and alkaline; the alkaline reaction disappears however on ebullition, triethylamine being disengaged. The crystals are likewise soluble in alcohol, but almost insoluble in ether.

The purification of the crystals is not attended with any difficulties; it is in fact sufficient to dissolve them in cold water and to allow the solution to evaporate spontaneously, when beautiful well-defined white crystals of considerable size are deposited, which may be easily separated by mechanical means, from small quantities of a reddish iodine-compound, which is sometimes formed by the action of the air. This latter substance is formed in much larger quantity at higher temperatures, wherefore it is advisable to avoid the use of boiling water in the purification.

The crystals are anhydrous; when exposed to the temperature of boiling water they exhibit no change in weight. When submitted to analysis they gave the following results:—

I. 0·4385 grm. of substance gave 0·6015 grm. of carbonic acid and 0·3040 grm. of water.

II. 0·5538 grm. of substance gave 0·5050 grm. of iodide of silver.

III. 0·5205 grm. of substance gave 0·4752 grm. of iodide of silver.

IV. 0·5000 grm. of substance gave 0·4552 grm. of iodide of silver.

These numbers lead to the following percentage composition:—

	I.	II.	III.	IV.
Carbon	37·41	——	——	——
Hydrogen	7·71	——	——	——
Iodine	——	49·29	49·35	49·21

The simplest formula into which these results may be translated is

$$C_{16}H_{20}NI,$$

the theoretical values of which I subjoin for comparison with the experimental numbers.

	Theory.		Mean of Experiments.
16 equivs. of Carbon . . .	96·0	37·34	37·41
20 equivs. of Hydrogen . .	20·0	7·78	7·71
1 equiv. of Nitrogen . . .	14·0	5·45	——
1 equiv. of Iodine	127·1	49·43	49·28
1 equiv. of Iodine-compound	257·1	100·00	

Hence it would appear that the formation of the white crystals simply depends upon a direct combination of triethylamine with iodide of ethyl, for—

$$\underbrace{C_{12}H_{15}N}_{\text{Triethylamine.}}+\underbrace{C_4H_5I}_{\text{Iodide of Ethyl.}}=\underbrace{C_{16}H_{20}NI.}_{\text{New crystalline compound.}}$$

In perfect accordance with this formation is the change which the iodine-compound undergoes when subjected to the action of heat; when rapidly heated the crystals fuse and are decomposed, the products being triethylamine and iodide of ethyl, which form two layers in the receiver, but rapidly unite again to the original compound. In fact this recombination takes place to a considerable extent in the neck of the retort; so that when first I became acquainted with this substance, I was for some time under the impression that the iodine-compound might be volatilized without decomposition.

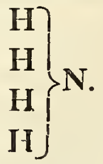
I confess I had not anticipated the possibility of the existence of a compound having the above composition; it appeared at the first glance in direct opposition to the theoretical view repeatedly referred to. For if it was possible to decompose the new iodide by potassa just as the preceding iodides, obtained respectively by the action of bromide (or iodide) of ethyl upon ammonia, ethylamine and diethylamine, if it was possible to separate from this substance a new volatile base analogous to the preceding ethylated alkaloids, there was no reason why the process of ethylation should cease with the fourth equivalent of ethyl. On the contrary, it then appeared more than probable, that the formations of ethylamine, diethylamine and triethylamine, far from being due to a successive replacement of the various equivalents of hydrogen in ammonia, were rather to be considered as special instances of a far more general tendency of carbon and hydrogen to accumulate in organic substances.

The eagerness with which I submitted this question to the test of experiment may be readily imagined. On adding potassa to a solution of the iodine-compound in water, the liquid solidified at once into a crystalline mass, which I took of course for the base existing in the iodide; analysis however soon showed that the substance thus precipitated is nothing but the iodide itself, which is less soluble in an alkaline solution than in pure water. In fact, Analysis IV. was made with a specimen which had thus been treated with potassa. The iodide was now distilled with a very concentrated solution of potassa for several hours; but during this time nothing but pure water passed over; the solution in the retort solidified on cooling to crystals of the unchanged iodide. When the solution of the iodide in potassa had become very concentrated, it separated into two layers, an aqueous one and an oily one, which floated on the surface. But even now no decomposition had been induced, the oily stratum solidifying on cooling into a crystalline cake of iodide perfectly unaltered. It was only when the liquid was evaporated to dryness that a change took place; but then the change was no longer due to the action of the potassa, but to the influence of heat, and in no way differed from the decomposition which the crystals undergo when heated alone.

The deportment with potassa of the new iodine-compound altogether precludes the idea of considering it as an analogue of the hydriodides of ethylamine, diethylamine, and triethylamine, all of which are readily decomposed under the influence of the alkalies.

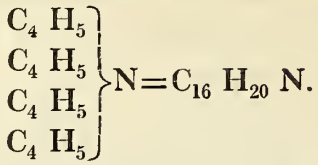
However, the iodine, though it cannot be eliminated from the crystals by the alkalies, may be separated with the greatest facility by silver-salts; in fact, the nitrate, the sulphate, the oxide of silver, behave with the iodine-compound exactly as with iodide of potassium or sodium. On adding nitrate of silver to a solution of the iodide, iodide of silver is at once precipitated and a nitrate remains in solution, which on evaporation crystallizes in deliquescent needles. With sulphate of silver, a perfectly similar change takes place, an analogous sulphate remaining in solution. During these interchanges the liquids remain perfectly neutral. If the solution of the iodide be digested with freshly precipitated protoxide of silver, the solution at once assumes a powerfully alkaline reaction, iodide of silver being formed: the same effect is produced by the action of caustic baryta upon the sulphate, sulphate of baryta being precipitated. These reactions, when viewed collectively, exhibit a striking analogy between the new iodide and the metallic iodides, especially those of the alkali-metals. In fact the molecular group combined with iodine, in the compound under examination, behaves like sodium or potassium; it is a true organic metal in all its bearings. For this metal I propose, on the ground of its formation and composition, the name Tetrethylammonium (τέτρα), which implies that it is built up by the intimate union of nitrogen with four equivalents of the hypothetical hydrocarbon called ethyl, and that it may be viewed as ammonium, in which the whole of the hydrogen is replaced by an equivalent proportion of the above hydrocarbon.

Ammonium.



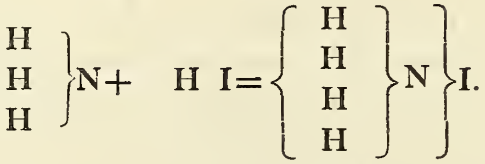
$$\left.\begin{array}{l}H\\H\\H\\H\end{array}\right\}N.$$

Tetrethylammonium.

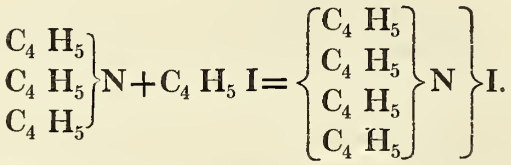


$$\left.\begin{array}{l}C_4H_5\\C_4H_5\\C_4H_5\\C_4H_5\end{array}\right\}N=C_{16}H_{20}N.$$

The new crystalline compound, according to this mode of viewing it, must be considered as iodide of tetrethylammonium, and its formation takes place in consequence of a transposition of the elements, which is perfectly analogous to that assumed by the followers of the ammonium-theory, in the formation of iodide of ammonium from ammonia and hydriodic acid.



$$\left.\begin{array}{l}H\\H\\H\end{array}\right\}N+\ H\,I=\left\{\left.\begin{array}{c}H\\H\\H\\H\end{array}\right\}N\right\}I.$$



$$\left.\begin{array}{l}C_4H_5\\C_4H_5\\C_4H_5\end{array}\right\}N+C_4H_5\,I=\left\{\left.\begin{array}{c}C_4H_5\\C_4H_5\\C_4H_5\\C_4H_5\end{array}\right\}N\right\}I.$$

I will not enter here into the merits of the ammonium-theory; the question whether this mode of representing the constitution of the ammonia-salts be correct or not, may be left out of consideration for the present. The view I have taken of the new compound, and which I readily admit must stand and fall with the ammonium-theory, has the great advantage of closely assimilating these substances to the compounds of mineral chemistry, whereby the nomenclature is essentially facilitated.

I will now proceed to give a sketch of the tetrethylammonium-compounds, as far as this is necessary, in order to convey a clear perception of the character and the peculiarities of this group of bodies. I reserve a detailed account of the derivatives of this group to a special memoir, in which I intend to give moreover a fuller description of diethylamine and triethylamine, which were only briefly noticed in my former paper.

Among the various substances derived from the new iodide, the corresponding oxide, the compound corresponding to oxide of ammonium, attracted my attention in a pre-eminent degree.

Oxide of Tetrethylammonium.

I have already briefly stated how this substance is prepared; on decomposing the iodide with an excess of sulphate of silver, a sulphate is obtained, from which sulphuric acid and excess of silver may be separated by baryta. This was in fact the first process by which I separated the base; it is, however, difficult to obtain the solution in this manner free from either baryta or sulphuric acid; nor have I ever used this process again, after I had found that digestion with freshly precipitated protoxide of silver produces at once the same effect. The oxide is added in small proportions to the solution of the iodide, which is gently heated; it is immediately converted into yellow iodide of silver, which assumes a white colour on stirring, as long as any undecomposed iodide is in solution. Gradually the yellow colour becomes permanent, and the decomposition is complete as soon as an excess of unchanged oxide becomes perceptible by its colour.

On filtering off the silver-precipitate, a clear and colourless liquid is obtained, which contains the isolated base in solution. It is of a powerfully alkaline reaction, which manifests itself, not only in its deportment with vegetable colours, but also in its possessing the pungent bitterness of quinine; the solution, when strongly concentrated, not only burns the tongue, but it acts upon the epidermis, which it destroys like caustic potassa or soda. On rubbing a solution of the oxide between the fingers, the well-known sensation produced by the fixed alkalies under the same circumstances is felt, and we perceive moreover the same peculiar odour.

Oxide of tetrethylammonium saponifies the fats as readily as potassa. The experiment was made with cocoa-nut oil, which after half an hour's ebullition with the new alkali was converted into a beautiful soft soap, having the appearance of an ordinary potassa-soap. This soap washes very well.

I have traced the analogy of the new body with potassa in many other directions. Chemists recollect the remarkable effect produced by ebullition with potassa in certain nitrogenous substances. It was by this process that Dr. Fownes, the discoverer of this reaction, converted furfuramide into the isomeric alkaloid, *furfurine*. I found that boiling with oxide of tetrethylammonium effects this molecular change as rapidly as potassa.

Like potassa it decomposes oxalic ether into oxalic acid and alcohol, and evolves ammonia from ammonia-salts, even in the cold. It may be substituted for potassa in Trommer's well-known sugar-test. Copper-solutions, mixed with either cane- or grape-sugar, yield on addition of oxide of tetrethylammonium, a light-blue precipitate of the hydrate of the protoxide, which redissolves in an excess of the base, forming a deep blue solution, with a shade of green; on ebullition the cane-sugar solution deposits a greenish precipitate, which is only slowly and always very incompletely converted into suboxide of copper. In the presence of grape-sugar the reduction ensues instantaneously on application of heat.

The reactions of the new base with metallic oxides assimilate this compound as nearly as possible to the fixed caustic alkalies. The following table exhibits the reactions of this body.

Barium-salts	White precipitate of the hydrate of the earth, insoluble in an excess of the base.
Strontium-salts . . .	White precipitate of the hydrate of the earth, insoluble in an excess of the base.

Calcium-salts	White precipitate of the hydrate of the earth, insoluble in an excess of the base.
Magnesium-salts	White precipitate of the hydrate of the earth, insoluble in an excess of the base.
Aluminum-salts	White gelatinous precipitate, soluble in a considerable excess of the base.
Chromium-salts	Greenish precipitate of the hydrated sesquioxide, insoluble in an excess of the base.
Nickel-salts	Apple-green hydrate of the protoxide, insoluble in excess.
Cobalt-salts	Pink hydrate of the protoxide, insoluble in excess.
Manganese-salts	Whitish precipitate of the hydrated protoxide, insoluble in excess.
Iron-salts.	
Protoxide	Green precipitate of the hydrated protoxide, insoluble in excess.
Sesquioxide	Brown precipitate of the hydrated sesquioxide, insoluble in excess.
Zinc-salts	White hydrate of the protoxide, soluble in excess.
Lead-salts	White hydrate of the protoxide, soluble in excess.
Silver-salts	Brown protoxide, insoluble in excess.
Mercury-salts.	
Suboxide	Black suboxide, insoluble in excess.
Protoxide	Red precipitate, probably of a double salt, becoming yellow protoxide by addition of excess.
Copper-salts	Blue hydrated protoxide, insoluble in excess, becoming black by ebullition.
Cadmium-salts	White hydrated protoxide, insoluble in excess.
Bismuth-salts	White hydrated teroxide, insoluble in excess.
Antimony-salts (Teroxide)	White hydrated teroxide, soluble in excess.
Tin-salts.	
Protoxide	White hydrated protoxide, soluble in excess.
Binoxide	White hydrated binoxide, soluble in excess.
Gold-salts	Yellow precipitate of the double compound.
Platinum-salts	Yellow precipitate of the double compound.

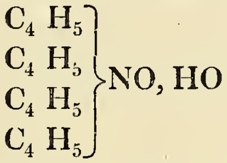
It is evident that the salts of the metals, with the exception of those of chromium, whose oxide does not redissolve in an excess of the base, exhibit the same reactions with potassa and oxide of tetrethylammonium.

Although I did not anticipate great results from the experiment, I have submitted the new base to the action of the galvanic current, the pile being disposed as in Berzelius's original experiment on the formation of the ammonium-amalgam.

However, no phenomenon, other than the decomposition of water, was observed. This decomposition certainly appeared to be facilitated, especially if the base was employed in the form of sulphate. Nor had potassium-amalgam the slightest effect upon oxide of tetrethylammonium.

I must still mention a peculiar reaction, somewhat singular at the first glance, which takes place on adding the concentrated oxide to alkaline solutions of iodide of potassium, when the crystalline iodide of tetrethylammonium is at once precipitated. I need scarcely remark that this phenomenon is due to the insolubility of the iodide in alkaline solutions, and not to the new base possessing a greater affinity for iodine than potassium, whose oxide is thus actually liberated.

A moderately concentrated solution of oxide of tetrethylammonium may be boiled without alteration; it is only in a very advanced stage of evaporation that decomposition gradually sets in. The change occurs even in the water-bath, as soon as the base becomes nearly dry. On evaporating, however, under the bell of the air-pump in the presence of sulphuric acid and lime, the base may be obtained in the dry state. I have endeavoured to obtain it in this manner in a condition fit for analysis, but all my attempts have been hitherto in vain; a concentrated solution of the oxide, when placed in a vacuum, deposits, after some days' exposure, long hair-like needles, which are, however, deliquescent in the extreme, and attract carbonic acid with great avidity. In both respects they are scarcely inferior to potassa. By remaining longer *in vacuo*, these crystals disappear again, and the whole liquid dries up to a semisolid mass, which also deliquesces rapidly, and becomes carbonated on exposure to the air. As there was not the slightest chance of getting this substance into a combustion-tube, I endeavoured to ascertain its composition, by decomposing a known quantity of the iodide with protoxide of silver, evaporating *in vacuo* in a glass dish, which on removing from the air-pump, could be covered with a glass plate, and determining the weight of the solid mass remaining. These experiments, however, have not led to any decisive results. Soon after the formation of the crystals, the liquid becomes coated with a thin pellicle, which retards the evaporation to such an extent, that even after a fortnight's exposure the mass still continues to lose in weight; but by that time, however carefully the air was excluded, the base has partly been converted into carbonate. Some similar experiments, made in the amyl-series, which I shall describe in another part of this paper, have been attended with more success. From these experiments it may be inferred by analogy, that the residue remaining on evaporating a solution of oxide of tetrethylammonium is the hydrate



$$\left.\begin{matrix} C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \end{matrix}\right\}NO,\,HO$$

corresponding to hydrate of potassa. The hair-like crystals contain evidently in addition several equivalents of water of crystallization; they may possibly be analogous to the well-known crystallized hydrate of potassa $KO, HO+4\ Aq$, which is formed at low temperatures.

It was above stated that the residuary substance left on evaporating a solution of the oxide of tetrethylammonium is decomposed, even at the temperature of boiling water. During this change a powerful ammoniacal odour is evolved, the substance strongly intumesces, and is by degrees perfectly volatilized. If this process be conducted in an appropriate apparatus, it is found that the base, under these circumstances, yields three products of decomposition, namely, water, an highly alkaline oil, rather soluble in water, and a colourless inflammable gas. The oily base has all the properties of triethylamine; it was identified moreover by the analysis of its characteristic platinum-salt.

0·2257 grm. of platinum-salt gave on ignition 0·0725 grm. of platinum.

	Theoretical percentage.	Experimental percentage.
Platinum	32·12	32·12

The inflammable gas evolved was pure olefiant gas; it was perfectly absorbed by bromine water, proving the absence of hydrocarbons not belonging to the family $C_n\ H_n$, and the oily liquid formed had all the properties of the Dutch liquid. It readily solidified into a crystalline mass when exposed to a freezing mixture, a deportment whereby the olefiant gas compound may be easily distinguished from the corresponding compounds of propylene, butylene and amylene.

Hence the metamorphosis of oxide of tetrethylammonium under the influence of heat is represented by the following equation:—

$$\left.\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \end{matrix}\right\} NO,\ HO = 2HO + \left\{\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \end{matrix}\right\} N + C_4H_4.$$

This change is not only interesting as an additional corroboration of the formula of the base, but likewise as affording a new source from which triethylamine may be obtained in a state of perfect purity; for as I shall show presently, the oxide may be also prepared from very impure mixtures of the lower ethyl-bases, and even from ammonia directly.

This, too, deserves to be noticed, as a new instance of the failure of the analogy between iodide and oxide of ethyl (ether)—a fact which was pointed out long ago by MM. Laurent and Gerhardt, and most indubitably demonstrated by the recent investigations of Dr. Williamson. If the decomposition by heat of oxide of tetrethylammonium was perfectly analogous to that of the iodide, we should expect to see the former split into triethylamine and oxide of ethyl (ether).

$$\left.\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \end{matrix}\right\} N\ I = \left\{\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \end{matrix}\right\} N + C_4\ H_5\ I.$$

$$\left.\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_4\,H_5\\C_4\,H_5\end{matrix}\right\}N\,O=\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_4\,H_5\end{matrix}\right\}N.+C_4\,H_5\,O.$$

But, as I have stated above, this decomposition yields, instead of ether, water and olefiant gas.

I have prepared several of the salts of tetrethylammonium. The sulphate, the nitrate, the phosphate, the carbonate, the hydrochlorate and the hydrobromate, all crystallize. But these salts are extremely soluble, and, with the exception of the carbonate, deliquescent, and but little adapted to analysis. They may be obtained either by directly saturating the oxide with the respective acids, or by double decomposition. The phosphate is conveniently prepared by gently heating a solution of the iodide with an excess of phosphate of silver, when, according to the silver-salt employed, either the common phosphate, or the pyrophosphate, &c. may be obtained. The phosphate thus obtained is strongly alkaline, like the tribasic soda-salt.

Tetrethylammonium forms a great number of beautiful double salts, of which I have examined a few.

Platinum-salt.—On adding a solution of bichloride of platinum to the chloride, an orange-yellow precipitate appears at once, which in every respect resembles the corresponding potassium- or ammonium-compound.

Like the latter, it is slightly soluble in water, and less so in alcohol and in ether; like the latter, it may be crystallized in beautiful octahedrons. The salt was repeatedly prepared. The specimens used for analysis I., II. and III., were precipitated from the pure chloride obtained by saturating the oxide with hydrochloric acid; specimens IV. and V., simply by removing the iodine from the iodide by nitrate of silver, acidifying with hydrochloric acid, and adding bichloride of platinum to the mixture of nitrate and chloride thus obtained. The latter circumstance may have caused the trifling discrepancy, which will be observed in the numbers below.

I. 0·3837 grm. of platinum-salt gave 0·4065 grm. of carbonic acid, and 0·2100 grm. of water.

II. 0·3586 grm. of platinum-salt gave 0·1056 grm. of platinum.

III. 0·2784 grm. of platinum-salt gave 0·0816 grm. of platinum.

IV. 0·5228 grm. of platinum-salt gave 0·1526 grm. of platinum.

V. 0·6782 grm. of platinum-salt gave 0·1977 grm. of platinum.

	Percentage-composition.				
	I.	II.	III.	IV.	V.
Carbon . . .	28·89	——	——	——	——
Hydrogen . .	6·08	——	——	——	——
Platinum . .	——	29·48	29·35	29·19	29·16

The formula

$$C_{16}H_{20}NCl, PtCl_2 = \left.\left\{\begin{matrix} C_4H_5 \\ C_4H_5 \\ C_4H_5 \\ C_4H_5 \end{matrix}\right.\right\} NCl, PtCl_2$$

requires the following values, which I collate with the experimental numbers.

	Theory.		Mean of Experiment.
16 equivs. of Carbon	96	28·63	28·89
20 equivs. of Hydrogen . . .	20	5·95	6·08
1 equiv. of Nitrogen	14	4·20	——
3 equivs. of Chlorine	106·5	31·78	——
1 equiv. of Platinum	98·68	29·44	29·27
1 equiv. of Platinum-salt . .	335·18	100·00	

Gold-Salt.—It is formed by mixing the solution of the two chlorides, when a lemon-yellow precipitate takes place, which is but slightly soluble in cold water or hydrochloric acid. Before analysis it was recrystallized from boiling water. I was satisfied with a determination of the metal in this compound.

I. 0·2555 grm. of gold-salt gave 0·1075 grm. of gold.

II. 0·4344 grm. of gold-salt gave 0·1822 grm. of gold.

The formula

$$\left.\begin{matrix} C_4H_5 \\ C_4H_5 \\ C_4H_5 \\ C_4H_5 \end{matrix}\right\} NCl, AuCl_3$$

requires the following values:—

	Theory.		Mean of Experiment.
1 equiv. of Chloride of Tetrethylammonium	165·50	35·32	——
3 equivs. of Chlorine	106·50	22·72	——
1 equiv. of Gold	196·66	41·96	42·00
1 equiv. of Gold-salt	468·66	100·00	

Mercury-Salts.—a. *Chlorine-Compound.*—On adding an excess of protochloride of mercury to a nearly neutral solution of the chloride, a beautiful crystalline white precipitate is formed, which is soluble in water and in hydrochloric acid, especially on ebullition. From the boiling solution it is deposited on cooling in plates of a greasy appearance. The analysis refers to two different preparations, the same specimen being used for I. and II. The mercury was determined as protosulphide.

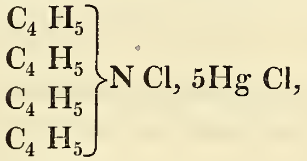
I. 0·4595 grm. of substance gave 0·3147 grm. of protosulphide of mercury.

II. 0·3960 grm. of substance gave 0·4020 grm. of chloride of silver.

III. 0·5530 grm. of substance gave 0·5580 grm. of chloride of silver.

	Percentage.		
	I.	II.	III.
Mercury	59·01	——	——
Chlorine	——	25·11	25·00

The only expression into which these numbers may be translated is the formula



$$\left.\begin{array}{l} C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \end{array}\right\} N\,Cl,\ 5Hg\,Cl,$$

which requires the following values:—

	Theory.		Mean of Experiment.
1 equiv. of Tetrethylammonium . .	130	15·49	——
6 equivs. of Chlorine	213	25·20	25·05
5 equivs. of Mercury	500	59·31	59·01
1 equiv. of Mercury-salt	843	100·00	

This somewhat peculiar composition, though chloride of mercury is known to join other compounds in rather unusual proportions, induced me to prepare an analogous iodine-compound, which on analysis was found to have a corresponding formula.

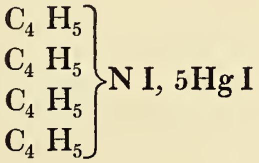
b. *Iodine-Compound.*—This substance was prepared in two different ways. Protiodide of mercury, when boiled with a solution of iodide of tetrethylammonium, loses at once its red colour, and is converted into a yellow compound, which fuses and collects as a transparent layer at the bottom of the vessel. On cooling it solidifies to a brittle mass, with crystalline fracture (I.). The same substance is obtained by adding a large excess of protochloride of mercury to a solution of iodide of tetrethylammonium. A whitish crystalline precipitate is produced, which consists of a mixture of the double salt just mentioned, with a large amount of the corresponding chlorine-compound*. By boiling with water the latter is removed, the former remaining behind (II.).

I. 0·7305 grm. of salt gave 0·7402 grm. of iodide of silver.

II. 0·8258 grm. of salt gave 0·8270 grm. of iodide of silver.

	Percentage.	
	I.	II.
Iodine	54·34	53·99

The formula



$$\left.\begin{array}{l} C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \end{array}\right\} N\,I,\ 5Hg\,I$$

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* 6 equivs. of iodide of tetrethylammonium and 30 equivs. of protochloride of mercury, contain the elements of 1 equiv. of the iodide of mercury double salt and of 5 equivs. of the chloride of mercury compound.

requires the following values :—

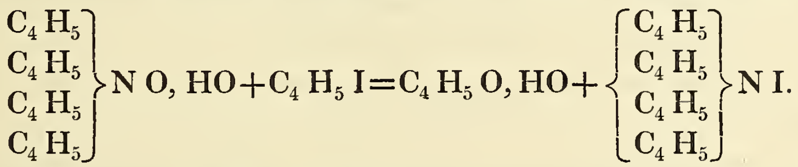
	Theory.		Mean of Experiment.
1 equiv. of Tetrethylammonium . . .	130·00	9·37	——
6 equivs. of Iodine	758·16	54·61	53·76
5 equivs of Mercury	500·00	36·02	——
1 equiv. of Mercury-salt	1388·16	100·00	

The new oxide forms several other double compounds; but as their analysis would have scarcely given additional elucidation to the subject, I have omitted to study them in detail.

The action of various chemical agents upon the compounds of tetrethylammonium gives rise to a series of very remarkable substances. Chlorine, bromine and iodine, convert the base into substitution-products, in which the basic character of the original atom has disappeared; of these the bromine-compound is distinguished by its splendid appearance, crystallizing as it does from alcohol in long magnificent orange-yellow needles. The iodine-compound, too, is very beautiful; it forms either on addition of iodine-solution to the base, or on evaporating a solution of the iodide exposed to the action of the air. In fact it is difficult to avoid the formation of this substance in recrystallizing iodide of tetrethylammonium. Cyanic acid yields with the base a crystalline compound, a sort of urea, which is remarkable for its composition, inasmuch as it may be viewed as ordinary urea, in which the four equivalents of hydrogen are replaced by ethyl. I hope to communicate shortly a full account of these several substances.

The preceding sketch, incomplete as it is, sufficiently exhibits the leading features of the new class of substances, of which tetrethylammonium and its compounds are the prototypes. It is at once evident that there is a marked difference between these latter and the bases which I have described in my former memoir. Irrespectively of the non-volatility of the new basic oxide, which forms in itself a line of demarcation, there are many other properties not less distinctive which attract our attention. The consecutive replacement of the several hydrogen-equivalents of ammonia induces a gradual change in the properties of the original atom; ethylamine is almost as soluble in water as ammonia itself; in diethylamine this property is less marked; and finally, triethylamine is still less soluble. But another equivalent of ethyl being added, the substance changes altogether in property; it becomes soluble in water in all proportions, in fact so soluble that it can scarcely be obtained in the dry state. A perfectly analogous, although reverse deportment, is exhibited by the platinum-salts of the various bases; here we find that the solubility of the salts augments with the degree of ethylation, the salt of triethylamine being soluble in the extreme, while suddenly the tetrethylammonium-compound becomes not more soluble than the ammonium-compound itself. It is evident that ethylamine, diethylamine and triethylamine are compound ammonias; the tetrethylated base is a compound oxide of ammonium.

It now remained only to submit the new base again to the action of iodide of ethyl. An experiment on a small scale showed that the two compounds do not fail to act promptly upon one another. The mixture, after an hour's ebullition in a sealed tube, solidified into a beautiful crystalline mass. In order to obtain a precise notion of this reaction, I repeated this experiment upon a grand scale. Two ounces of iodide of tetrethylammonium were caustified by protoxide of silver, and then submitted to the action of about half a pound of iodide of ethyl. The mixture was kept boiling in a glass flask, provided with a long tube, in which the volatilized substances were condensed and returned to the seat of the reaction. During the whole process not a trace of permanent gas was disengaged. After a day's ebullition the solution had become neutral, and deposited on cooling magnificent crystals of iodide of tetrethylammonium, which were identified by analysis. In fact, for the determinations III. and V., mentioned at the analysis of the platinum-compound, the salts had been prepared with the base obtained in this manner. On submitting the mother-liquor of the crystals to distillation in such a manner as to collect only the most volatile products, a considerable amount of perfectly pure alcohol was obtained, which was identified by a careful comparison of all its properties. The action of iodide of ethyl upon oxide of tetrethylammonium is therefore represented by the following equation—



$$\left.\begin{matrix}C_4H_5\\C_4H_5\\C_4H_5\\C_4H_5\end{matrix}\right\}N\,O, HO+C_4H_5\,I=C_4H_5\,O, HO+\left\{\begin{matrix}C_4H_5\\C_4H_5\\C_4H_5\\C_4H_5\end{matrix}\right\}N\,I.$$

I have since found that metallic oxides, such as protoxide of silver, in the presence of water, all exert the same action on iodide of ethyl; in this case a metallic iodide is formed, alcohol being reproduced.

The experiment just described shows that, as might have been expected, the ethylation cannot be carried on *ad infinitum*, and that the oxide of tetrethylammonium is the highest term attainable in the ethyl-series. The latter substance continues to act upon iodide of ethyl, but the change affects solely the iodide of ethyl, while the base is no longer altered.

The preceding researches are, in themselves, sufficient to establish the point of theory which is here in question; still I hoped to gain a broader basis for raising general conclusions by collecting some additional facts. The repetition in the methyl- or amyl-series of an experiment already made in the ethyl-series, resembles, it is true, the working of a design in blue or green, which has been previously printed in red. Nevertheless, irrespectively of the farther elaboration of the theory of homologues, which is still wanted, such experiments lead frequently to new and unexpected observations, which often amply repay the trouble and tediousness of such inquiries. I therefore made the experiments which yielded the following results:—

Action of Iodide of Methyl upon Triethylamine.

A mixture of triethylamine and iodide of methyl solidifies, after some time, to a crystalline mass, even at the common temperature. On ebullition the change takes place instantaneously. The crystalline compound thus produced may be viewed as the iodide of an organic metal, containing, together with nitrogen, one equivalent of methyl, and three of ethyl.

$$\left.\begin{array}{l}C_4\,H_5\\C_4\,H_5\\C_4\,H_5\end{array}\right\}N+C_2\,H_3\,I=\left\{\begin{array}{l}C_2\,H_3\\C_4\,H_5\\C_4\,H_5\\C_4\,H_5\end{array}\right\}N\,I.$$

In accordance with the nomenclature I have proposed for the preceding substance, this compound may be called iodide of methylotriethylammonium. And here is perhaps the place to ask for indulgence, for the *sesquipedalia verba*, which I am using in the account of this investigation, and of which the worst, I fear, are still to come. However, the use of these barbarous names has the advantage of conveying an idea of the composition of the substances under examination in the shortest and most impressive manner. Moreover, none of these names are likely to remain in science; all these substances, which are prepared solely for the elucidation of a principle, will be forgotten as soon as the object is gained; they resemble paving-stones, each of which is very important in laying down a street, though no interest is attached to the blocks themselves, as soon as we are passing along the level road.

Iodide of methylotriethylammonium has all the properties which I have enumerated when speaking of the preceding compound. It is extremely soluble, forming a perfectly neutral, very bitter solution. On adding potassa to this solution, a heavy oily liquid is precipitated, which gradually solidifies. This is the unchanged iodide, which, like the corresponding tetrethylammonium-compound, is less soluble in alkaline solutions than in water. The iodide is readily decomposed by protoxide of silver, whereby the oxide is obtained in solution, which is caustic and bitter in the extreme. *In vacuo* it dries up to a crystalline compound, analogous to oxide of tetrethylammonium, the properties of which present the same difficulties to analysis. I have fixed the composition of this compound by the analysis of the beautiful platinum-precipitate, which is formed on adding the bichloride to a solution of the base saturated with hydrochloric acid.

0·3530 grm. of platinum-salt gave 0·1075 grm. of platinum.

To the formula

$$C_{14}\,H_{18}\,N\,Cl,\,Pt\,Cl_2=\left\{\begin{array}{l}C_2\,H_3\\C_4\,H_5\\C_4\,H_5\\C_4\,H_5\end{array}\right\}N\,Cl,\,Pt\,Cl_2$$

correspond the following values:—

	Theory.		Experiment.
1 equiv. of Methylotriethylammonium .	116·00	36·15	——
3 equivs. of Chlorine	106·50	33·15	——
1 equiv. of Platinum	98·68	30·70	30·48
1 equiv. of Platinum-salt	321·18	100·00	

I have not studied this substance very minutely; it forms crystalline salts with sulphuric, nitric, oxalic and hydrochloric acids.

ACTION OF IODIDE OF AMYL UPON TRIETHYLAMINE.

The experiment was conducted in a perfectly similar manner, and the results obtained are perfectly analogous. The action however is by no means as rapid as in the preceding cases, the amyl-substances being invariably much more inert than the corresponding terms in the ethyl- and methyl-series. In order to complete the process, it is necessary to heat the mixture in sealed tubes for two or three days. The iodide of amylotriethylammonium, for this is the new compound, forms remarkably fine crystals, which exhibit the fatty lustre and touch peculiar to the amyl-compounds. It is extremely soluble in water and alcohol, insoluble in ether. The solutions have the bitter taste of quinine. On adding potassa or carbonate of potassa, the iodide separates as an oil, which rapidly shoots into brilliant needles. The salt when slightly moist fuses at 100° C. to a clear oily liquid, which becomes solid on cooling and perfect desiccation, and gradually assumes a yellow tint.

The iodine-determination gave the following result:—

0·4210 grm. of iodide gave 0·3310 grm. of iodide of silver.

The formula

$$C_{22}\,H_{24}\,N\,I = \left.\left\{\begin{matrix} C_4 & H_5 \\ C_4 & H_5 \\ C_4 & H_5 \\ C_{10} & H_{11} \end{matrix}\right.\right\}N\,I$$

requires the following values:—

	Theory.		Experiment.
1 equiv. of Amylotriethylammonium . . .	172·0	57·51	——
1 equiv. of Iodine	127·1	42·49	42·51
1 equiv. of Iodine-compound	299·1	100·00	

When boiled with protoxide of silver the base is liberated and dissolves, forming an alkaline liquid of extremely bitter taste. The alkaline properties are however less marked than in the preceding bases. On evaporation the oxide of amylotriethylammonium remains in form of a syrup, which I have never seen assuming the crystalline form, perhaps because I have not allowed it to stand for a sufficiently long time. The sulphate and oxalate of this base, when evaporated in the bell of the air-pump, leave a syrupy or gummy residue like the base itself. The nitrate, however, and the hydrochlorate form beautiful crystals, the former hard, permanent needles of a cooling taste; the latter, leaves which are extremely deliquescent. The solution of the hydrochlorate is not precipitated by bichloride of platinum unless very concentrated. The salt once formed however is far less soluble. From a boiling solution in water it shoots into most magnificent orange-yellow needles, sometimes half an inch in length.

On ignition, 0·2620 grm. of platinum-salt gave 0·0675 grm. of platinum.

The values corresponding to the formula

$$C_{22}\,H_{26}\,N\,Cl,\ Pt\,Cl_2 = \left\{\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \\ C_{10}\ H_{11} \end{matrix}\right\} N\,Cl,\ Pt\,Cl_2$$

are

	Theory.		Experiment.
1 equiv. of Amylotriethylammonium . . .	172·00	45·60	——
3 equivs. of Chlorine	106·50	28·24	——
1 equiv. of Platinum	98·68	26·16	25·76
1 equiv. of Platinum-salt	377·18	100·00	

The percentage of the platinum is unusually low when compared with the theoretical value, a fact which I suppose is due to the recrystallization of the salt. In several cases I have observed that the platinum-salts of these bases undergo a slight decomposition under these circumstances, which is not indicated by the appearance of the recrystallized salt, but which is invariably pointed out by a diminution of the amount of platinum. I am not as yet acquainted with the mode of this change. In the present instance I have not repeated the experiment, because the mode of formation, the analysis of the iodide, and moreover the decomposition of the base, preclude all doubts respecting the formula of the compound under examination.

The remarkable change exhibited by oxide of tetrethylammonium, when submitted to the action of heat, necessarily induced me to study the deportment of the amylotriethylated base under similar circumstances. This study appeared to promise some farther revelations respecting the molecular constitution of this body, a hope in which I was not deceived. I had no doubt in my mind that the process alluded to would give rise to the formation of a nitrile-base, but there were two alternatives which presented themselves as to the nature of this base. The question arose, Will an equivalent of ethyl or amyl be broken up in this decomposition? This question had to be decided by experiment.

ACTION OF HEAT ON OXIDE OF AMYLOTRIETHYLAMMONIUM.

Oxide of amylotriethylammonium, when subjected to distillation, begins to froth as soon as the solution becomes concentrated, after which decomposition rapidly sets in. The products of this decomposition are water, an oily substance, and a transparent inflammable gas. The latter, by the method I have indicated when speaking of the decomposition of oxide of tetrethylammonium, was proved to be perfectly pure olefiant gas, when the composition of the oily liquid was no longer doubtful. It was evident that this substance must be a nitrile-base containing two equivalents of ethyl and one equivalent of amyl.

$$\left.\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \\ C_{10}\ H_{11} \end{matrix}\right\} NO,\ HO = 2HO + \left\{\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_{10}\ H_{11} \end{matrix}\right\} N + C_4\ H_4.$$

Experiment has entirely confirmed this view. Diethylamylamine—for this is the name which appertains to the new compound—has a peculiar, not unpleasant aromatic odour, and an analogous somewhat bitter taste, is lighter than water, in which it scarcely dissolves, imparting to it a slight but decided alkaline reaction. It combines with acids less readily than do the bases which occupy a lower position in the system. The salts with sulphuric, nitric, oxalic and hydrochloric acids, crystallize beautifully, but are deliquescent. Diethylamylamine, when dried over hydrate of potassa and rectified, exhibits a perfectly constant boiling-point at 154° C.

I have fixed the composition of this base, as usual, by the analysis of the platinum-salt. This compound is obtained by concentrating a mixture of the hydrochlorate with bichloride of platinum, when it shoots into long magnificent orange-yellow prisms.

I. 0·3405 grm. of platinum-salt gave 0·0955 grm. of platinum.

II. 0·3805 grm. of platinum-salt gave 0·1065 grm. of platinum.

	Percentage.	
	I.	II.
Platinum	28·04	28·02

The formula

$$C_{18}\ H_{21}\ N,\ HCl,\ Pt\ Cl_2 = \left\{\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_{10}\ H_{11} \end{matrix}\right\} N,\ H\ Cl,\ Pt\ Cl_2$$

requires

	Theory.		Experiment.
1 equiv. of Hydrochlorate of Diethylamylamine .	179·50	51·40	——
2 equivs. of Chlorine	71·00	20·34	——
1 equiv of Platinum	98·68	28·26	28·03
1 equiv. of Platinum-salt	349·18	100·00	

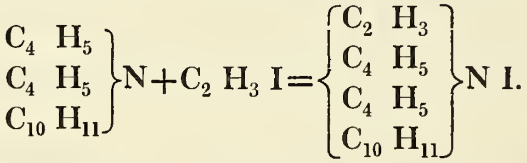
The formula of diethylamylamine is moreover supported by the boiling-point. This compound differs from diethylamine by $C_{18}\ H_{21}\ N-C_8\ H_{11}\ N=C_{10}\ H_{10}=5C_2\ H_2$. I have lately prepared diethylamine on a larger scale, and found its boiling-point to be 57° C.; on starting from this number, the boiling-point of diethylamylamine should be $57+(5\times 19)=152°$. The experimental boiling-point is 154°.

Having seen by the preceding experiments that ethyl, as it were, yields its place to amyl, the idea naturally suggested itself to inquire into the mutual relations of ethyl and methyl under similar circumstances. For this purpose I might have studied the action of heat upon oxide of methylotriethylammonium; however, as I had some grammes of diethylamylamine at my disposal, I preferred to methylate this compound, and examine the new body thus obtained.

Action of Iodide of Methyl upon Diethylamylamine.

On adding iodide of methyl to diethylamylamine, the phenomena which I have already several times described are repeated in turn. The action in this case however is so violent that the iodide must be added very gradually, for on suddenly mixing, the liquid is projected from the vessel with a sort of explosion; on account of the low boiling-point of the methyl-compound, it is advisable to mix in a tubulated retort provided with a condenser.

On cooling the mixture solidifies into a hard white crystalline mass, consisting of a new iodide, for which, in accordance with the nomenclature which I have adopted, I propose the name iodide of methylodiethylamylammonium.



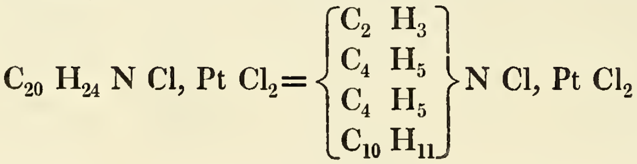
$$\left.\begin{array}{l}C_4\ H_5\\ C_4\ H_5\\ C_{10}\ H_{11}\end{array}\right\}N+C_2\ H_3\ I=\left\{\begin{array}{l}C_2\ H_3\\ C_4\ H_5\\ C_4\ H_5\\ C_{10}\ H_{11}\end{array}\right\}N\ I.$$

The new iodide, like the preceding analogues, is extremely soluble in water, forming a very bitter solution, from which it is reprecipitated by potassa in oily globules, which solidify again but slowly.

When digested with protoxide of silver, the iodide yields the oxide in form of a powerful alkaline solution, which forms crystalline salts with sulphuric, nitric and hydrochloric acid. The hydrochlorate of methylodiethylamylammonium gives with bichloride of platinum a beautiful salt, by the analysis of which the composition of the substance was established.

0·2015 grm. of platinum-salt gave 0·0550 grm. of platinum.

The values corresponding to the formula



$$C_{20}\ H_{24}\ N\ Cl,\ Pt\ Cl_2=\left\{\begin{array}{l}C_2\ H_3\\ C_4\ H_5\\ C_4\ H_5\\ C_{10}\ H_{11}\end{array}\right\}N\ Cl,\ Pt\ Cl_2$$

are the following:—

	Theory.		Experiment.
1 equiv. of Methylodiethylamylammonium . .	158·00	43·50	——
3 equivs. of Chlorine	106·50	29·33	——
1 equiv. of Platinum	98·68	27·17	27·29
1 equiv. of Platinum-salt	363·18	100·00	

Action of Heat upon Oxide of Methylodiethylamylammonium.

When submitted to distillation this compound is decomposed like the analogous substances, the product being water, pure olefiant gas, which was identified as formerly, and a very remarkable nitrile-base, containing the three different alcohol-radicals, an ammonia, in fact, in which the first equiv. of hydrogen is replaced by methyl, the second by ethyl, the third by amyl, and which receives the name methylethylamylamine.

$$\left.\begin{matrix} C_2\ H_3 \\ C_4\ H_5 \\ C_4\ H_5 \\ C_{10}\ H_{11} \end{matrix}\right\} NO,\ HO = 2HO + \left\{\begin{matrix} C_2\ H_3 \\ C_4\ H_5 \\ C_{10}\ H_{11} \end{matrix}\right\} N + C_4H_4.$$

This reaction shows that ethyl yields its place even to methyl, a fact which could not have been anticipated from analogy, methyl occupying a lower position than ethyl in the system. The above deportment is moreover remarkable, when considered in another point of view. The elimination of methyl in the case under examination would have given rise to the formation of methylene* $C_2\ H_2$, a substance the existence of which is still very problematical.

Methylethylamylamine is a transparent oil of a fragrant odour and an analogous taste. Both these properties are much more marked than those of diethylamylamine, which it resembles in most respects. It is somewhat more soluble in water than the latter, and of a more decided alkaline character. When dried over potassa and rectified, the new base boils constantly at 135°. Hence its boiling-point is $154-135=19°$ lower than that of diethylamylamine, a difference which is in perfect accordance with H. Kopp's rule.

Methylethylamylamine dissolves but slowly in the acids, forming salts which resemble those of the diethylamylated bases. The hydrochlorate gives with bichloride of platinum a beautiful double salt, which is extremely soluble in water. It is usually precipitated on mixing the highly concentrated solutions, or on evaporating the mixture, in oily globules of a deep orange-yellow, which gradually solidify into magnificent needles.

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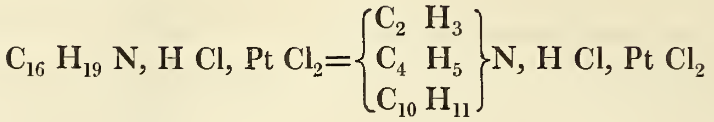
* In their paper on Methylalcohol, Dumas and Peligot (Ann. Ch. Phys. [2] lviii. 5) state that methylene is formed by passing the vapour of chloride of methyl through a red-hot tube. The gas obtained by this process did not however very accurately exhibit the composition $C_n\ H_n$, nor are any experiments for the determination of the value of n recorded.

On analysis 0·4155 grm. of platinum-salt gave 0·1212 grm. of platinum.

The formula



$$C_{16}H_{19}N, HCl, PtCl_2 = \left.\begin{matrix} C_2H_3 \\ C_4H_5 \\ C_{10}H_{11} \end{matrix}\right\} N, HCl, PtCl_2$$

requires

	Theory.		Experiment.
1 equiv. of Hydrochlorate of Methylethylamylamine	165·50	49·38	——
2 equivs. of Chlorine	71·00	21·18	——
1 equiv. of Platinum	98·68	29·44	29·36
1 equiv. of Platinum-salt	335·18	100·00	

In the preceding experiments, the radicals of the alcohols $C_n H_{(n+2)} O_2$ have been exclusively used as replacing materials. However, as might have been expected, nitrile-bases containing a radical which is not homologous but only analogous to the two others, exhibit exactly the same deportment when submitted to the action of iodide of methyl, of ethyl or of amyl. In order to establish this point, I had to return once more to the aniline-series.

Action of Iodide of Ethyl upon Diethylaniline.

In my former paper* I have recorded a few experiments on the action of bromide of ethyl upon diethylaniline. The results, unintelligible to me at that period, are now perfectly clear. I have since repeated these reactions, substituting the iodide for the bromide on account of its more prompt action. Diethylaniline is perfectly soluble in iodide of ethyl; on exposing the mixture, sealed in tubes, to the temperature of boiling water, the liquid column gradually separates into two layers, the lower one increasing in bulk with the time of exposure, and solidifying on cooling into a semi-solid crystalline mass. The reaction is terminated, when, after half a day's ebullition, the volume of the lower layer, which is the new iodide in the fused state, ceases to increase.

The mixture is now distilled with water in order to separate an excess of either diethylaniline or iodide of ethyl, when a strongly acid solution of iodide of phenylotriethylammonium is obtained, which usually contains a small quantity of hydriodate of diethylaniline, as may be inferred from the oily precipitate produced in the solution by potassa, which does not redissolve on addition of more water.

Digestion with protoxide of silver separates the two bases, one of which, diethylaniline, being insoluble in water, remains mixed with the oxide and iodide of silver; the other, the oxide of phenylotriethylammonium, forming a powerfully alkaline solution of a strongly bitter taste.

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* Philosophical Transactions, 1850, Part I. p. 107.

After having ascertained by treatment with ether that the solution did not retain a trace of diethylaniline, it was saturated with hydrochloric acid and mixed with bichloride of platinum, when at once a pale-yellow, apparently amorphous precipitate was thrown down, which was scarcely soluble in water and insoluble in alcohol and ether.

0·4055 grm. of platinum-salt gave 0·1045 grm. of platinum.

To the formula

$$C_{24}H_{20}NCl, PtCl_2 = \left.\left\{\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \\ C_{12}H_5 \end{matrix}\right\}\right. NCl, PtCl_2$$

correspond the following values :—

	Theory.		Experiment.
1 equiv. of Phenylotriethylammonium . .	178·00	46·45	——
3 equivs. of Chlorine	106·50	27·80	——
1 equiv. of Platinum	98·68	25·75	25·77
1 equiv. of Platinum-salt	383·18	100·00	

I have not examined any farther the compounds of this base; I have only ascertained that the sulphate, nitrate, oxalate and hydrochlorate crystallize, although with difficulty.

When oxide of phenylotriethylammonium is submitted to the action of heat, it yields, as might have been expected, water, olefiant gas and diethylophenylamine (diethylaniline).

$$\left.\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_4\ H_5 \\ C_{12}H_5 \end{matrix}\right\} NO, HO = 2HO + \left\{\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_{12}H_5 \end{matrix}\right\} N + C_4H_4.$$

The olefiant gas was identified by the conversion into the bromine-compound, the diethylaniline by the analysis of the characteristic platinum-salt.

0·2965 grm. of platinum-salt gave 0·0820 grm. of platinum.

This corresponds to 27·65 per cent. of platinum.

The formula

$$C_{20}H_{15}N, HCl, PtCl_2 = \left\{\begin{matrix} C_4\ H_5 \\ C_4\ H_5 \\ C_{12}H_5 \end{matrix}\right\} N, HCl, PtCl_2$$

requires 27·78 per cent. of platinum.

Action of Iodide of Methyl upon Ethylamylaniline.

Ethylamylaniline, which I formerly obtained* by the action of bromide of amyl upon ethylaniline, or of bromide of ethyl upon amylaniline, may be formed with the same, or greater facility, by exposing the latter base to iodide of ethyl. When submitted to the action of iodide of methyl at the temperature of boiling water for three or four days, ethylamylaniline exhibits all the phenomena described in the preceding paragraph. The lower layer, which solidifies, is a mixture of hydriodate of ethylamylaniline and iodide of methylethylamylophenylammonium. *Sit venia verbo!*

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* Philosophical Transactions, 1850, Part I. p. 117.

$$\left.\begin{matrix} C_4\,H_5 \\ C_{10}\,H_{11} \\ C_{12}\,H_5 \end{matrix}\right\} N + C_2\,H_3\,I = \left\{\begin{matrix} C_2\,H_3 \\ C_4\,H_5 \\ C_{10}\,H_{11} \\ C_{12}\,H_5 \end{matrix}\right\} N\,I.$$

The corresponding oxide is obtained as the preceding one, namely, by treating the clear solution of the two iodine-compounds, previously freed by ebullition from an excess of iodide of methyl, or ethylamylaniline, with protoxide of silver, when unchanged ethylamylaniline and the base with the long name separate. The latter remaining in solution (and forming a very bitter liquid of a strongly alkaline reaction), whilst the former is insoluble, there was no difficulty in obtaining a pure platinum-salt whereby to prove the composition of the compound in question. This salt is a pale-yellow amorphous precipitate, very slightly soluble in water.

On analysis—

0·4335 grm. of the platinum-salt gave 0·1045 grm. of the platinum.

I collate the percentage number corresponding to this result with the theoretical value of the formula—

$$C_{28}\,H_{24}\,N\,Cl,\,Pt\,Cl_2 = \left\{\begin{matrix} C_2\,H_3 \\ C_4\,H_5 \\ C_{10}\,H_{11} \\ C_{12}\,H_5 \end{matrix}\right\} N\,Cl,\,Pt\,Cl_2.$$

	Theory.		Experiment.
1 equiv. of Methylethylamylophenylammonium . .	206·00	50·01	——
3 equivs. of Chlorine	106·50	26·00	——
1 equiv. of Platinum	98·68	23·99	24·11
1 equiv. of Platinum-salt	411·18	100·00	

This compound is certainly remarkable for the diversity of its components, for it contains the radicals of not less than four different alcohols!

As to the action of heat upon the oxide under examination, there could be scarcely any doubt after the result of the preceding investigation. Still I have established by experiment that in this reaction olefiant gas is eliminated, whilst a new nitrile-base, containing methyl, amyl and phenyl, is generated.

$$\left.\begin{matrix} C_2\,H_3 \\ C_4\,H_5 \\ C_{10}\,H_{11} \\ C_{12}\,H_5 \end{matrix}\right\} N\,O,\,H\,O = 2H\,O + \left\{\begin{matrix} C_2\,H_3 \\ C_{10}\,H_{11} \\ C_{12}\,H_5 \end{matrix}\right\} N + C_4\,H_4.$$

Methylamylophenylamine is an oil of an odour similar to that of amylaniline; it is almost insoluble in water: I have not prepared enough of this compound to determine the boiling-point, which at all events is very high. It forms a crystalline platinum-salt, whose analysis was sufficient to establish its composition.

0·3795 grm. of platinum-salt gave 0·0866 grm. of platinum.

The formula

$$C_{24}H_{19}N, HCl, PtCl_2 = \left.\begin{cases} C_2\,H_3 \\ C_{10}H_{11} \\ C_{12}H_5 \end{cases}\right\} N, HCl, PtCl_2,$$

requires the following values:—

	Theory.		Experiment.
1 equiv. of Hydrochlorate of Methylamylaniline	213·5	55·72	——
2 equivs. of Chlorine	71·0	18·53	——
1 equiv. of Platinum	98·68	25·75	25·81
1 equiv. of Platinum-salt	383·18	100·00	

The paragraphs now following are devoted to a brief account of several bases belonging to the methyl- and amyl-series.

Bases of the Methyl-series.

The experiments described under this head were originally undertaken by my friend Captain Reynolds, who by many occupations unfortunately was prevented from continuing the investigation, so that I am obliged to take alone the responsibility of the following statements.

ACTION OF AMMONIA UPON IODIDE OF METHYL.

If iodide of methyl be treated with a concentrated aqueous solution of ammonia, the former is rapidly dissolved, the completion of the reaction being indicated by the liquid assuming a yellowish tint. On opening the boiler-tube the liquid is found to be strongly acid, and to contain not less than five different iodides, namely—

Iodide of Ammonium . . . . $\left.\begin{cases} H \\ H \\ H \\ H \end{cases}\right\} NI.$

Iodide of Methylammonium . . . . $\left.\begin{cases} H \\ H \\ H \\ C_2H_3 \end{cases}\right\} NI.$

Iodide of Dimethylammonium . . . . $\left.\begin{cases} H \\ H \\ C_2H_3 \\ C_2H_3 \end{cases}\right\} NI.$

Iodide of Trimethylammonium . . . . . . $\left.\begin{array}{c} H \\ C_2\,H_3 \\ C_2\,H_3 \\ C_2\,H_3 \end{array}\right\} N\,I.$

Iodide of Tetramethylammonium . . . . . . $\left.\begin{array}{c} C_2\,H_3 \\ C_2\,H_3 \\ C_2\,H_3 \\ C_2\,H_3 \end{array}\right\} N\,I.$

Of these five compounds, the first and the last are formed in considerable excess. Of the remainder I have as yet only been able to establish the presence of the iodide of methylammonium by numbers. The two others I have not as yet obtained in sufficiently large quantity and of the requisite purity. The solution of this mixture deposits, on cooling, magnificent dazzling-white hard flat needles, sometimes of an inch in length, which are very difficultly soluble in cold water, and may be obtained in the state of purity by washing with cold and recrystallizing from boiling water. These crystals are the iodide of tetramethylammonium, all the other salts remaining in the mother-liquor, which rapidly turns brown on exposure to the atmosphere. The facility with which ammonia acts upon iodide of methyl, renders it unnecessary to perform the process at a high temperature. The reaction is accomplished after some days, even at the common temperature, if an alcoholic solution be employed, after some hours, a considerable amount of heat being disengaged.

Iodide of Tetramethylammonium.

This substance possesses the family-features of the group. It is soluble in water, but far less so than the corresponding ethyl-compound, forming a perfectly neutral solution of an extremely bitter taste. It is almost insoluble in absolute alcohol, insoluble in ether. Like the ethyl-compounds, this salt is far less soluble in potassa than in pure water.

On analysis the following results were obtained:—

I. 0·4753 grm. of iodide gave 0·5519 grm. of iodide of silver.
II. 0·4256 grm. of iodide gave 0·4973 grm. of iodide of silver.

	Percentage.	
	I.	II.
Iodine	62·75	63·14

The formula

$$C_8\,H_{12}\,N\,I = \left\{\begin{array}{c} C_2\,H_3 \\ C_2\,H_3 \\ C_2\,H_3 \\ C_2\,H_3 \end{array}\right\} N\,I$$

requires the following values:—

	Theory.		Experiment.
1 equiv. of Tetramethylammonium . .	74·0	36·75	——
1 equiv. of Iodine	127·1	63·25	62·94
1 equiv. of Iodine-compound	201·1	100·00	

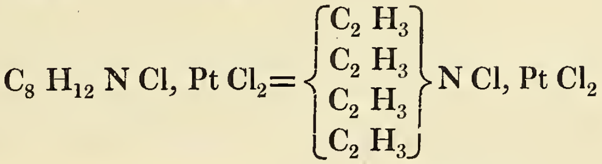
The action of protoxide of silver upon the iodine-compound is perfectly analogous to that which it exerts upon the ethyl-body. The oxide of tetramethylammonium thus liberated is endowed with scarcely less marked properties than the ethyl-base. When evaporated over sulphuric acid *in vacuo,* it likewise dries up to a crystalline mass, attracting moisture and carbonic acid with the greatest avidity; saturated with acids, it yields crystallizable salts. I have prepared the sulphate, oxalate, nitrate and chloride; the nitrate especially crystallizes well, in long brilliant needles.

The chloride yields with bichloride of platinum a magnificent double salt, which is less insoluble than the corresponding salt in the ethyl-series; it crystallizes in perfectly regular octohedrons of a deep orange colour. When recrystallized from boiling water, this salt exhibits the peculiarity to which I have alluded previously (see p. 374), of yielding a smaller percentage of platinum. Analysis I. was made with the precipitated, analysis II. and III. with the recrystallized salt.

I. 0·2695 grm. of platinum-salt gave 0·0950 grm. of platinum.
II. 0·1925 grm. of platinum-salt gave 0·0670 grm. of platinum.
III. 0·3420 grm. of platinum-salt gave 0·1190 grm. of platinum.

	Percentage.		
	I.	II.	III.
Platinum	35·21	34·86	34·79

Values corresponding to the formula:—



$$C_8\,H_{12}\,N\,Cl,\,Pt\,Cl_2=\left.\begin{cases}C_2\,H_3\\C_2\,H_3\\C_2\,H_3\\C_2\,H_3\end{cases}\right\}N\,Cl,\,Pt\,Cl_2$$

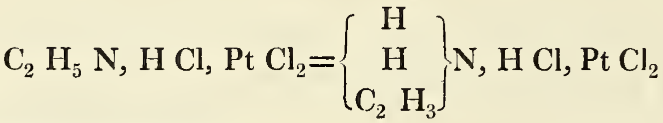
	Theory.		Experiment.
1 equiv. of Tetramethylammonium . .	74·00	26·50	——
3 equivs. of Chlorine	106·50	38·15	——
1 equiv. of Platinum	98·68	35·35	35·21
1 equiv. of Platinum-salt	279·18	100·00	

I was exceedingly desirous to submit this oxide to the action of heat; for this process, provided the methyl-base followed the deportment of its ethyl-fellow, promised to give me the long-desired methylene $C_2\,H_2$. Oxide of tetramethylammonium, when heated violently, intumesces, and is completely volatilized; the product of the distillation is an extremely volatile and powerfully alkaline liquid; but. strange to say, during the whole process not a trace of gas is disengaged. I have repeatedly performed the experiment with exactly the same result. Here then we meet with a new mode of decomposition, and unless I am much mistaken, with a decomposition of a very peculiar character. I have made a few experiments with the basic liquid disengaged, but as I have not as yet arrived at perfectly definite results, I refrain from entering into farther details.

The mother-liquor of iodide of tetramethylammonium, which contains chiefly iodide of ammonium, together with small quantities of the intermediate iodides, yields all the corresponding bases by distillation with potassa. However, the ammonia prevails in the distillate to such an extent, that the attempt to effect a separation would have been hopeless. It was only by precipitating the liquid with bichloride of platinum, and separating the more soluble from the less soluble salts, that I succeeded in obtaining evidence of the presence of the intermediate bases. As yet I have been able to prepare only the methylamine-salt in a state of tolerable purity, of which I subjoin the analysis.

0·1415 grm. of platinum-salt gave 0·0590 grm.=41·69 per cent. of platinum.

The formula



$$C_2\,H_5\,N,\,H\,Cl,\,Pt\,Cl_2=\left.\begin{cases}H\\H\\C_2\,H_3\end{cases}\right\}N,\,H\,Cl,\,Pt\,Cl_2$$

requires 41·61 per cent. of platinum.

Bases of the Amyl-Series.

While I was engaged with the investigation of the lower ethyl-bases, Messrs. William and Alfred Bennett, who at that period were studying in the Laboratory of the College of Chemistry, undertook, at my request, the examination of the corresponding bodies in the amyl-series. Prevented from completing their researches by leaving London, these gentlemen have placed their results at my disposal, which I have verified in every respect, and which I subjoin, together with a series of experiments of my own, especially on the oxide of tetramylammonium.

Amylamine.

Ammonia acts but very slowly upon iodide of amyl, and the product of the reaction contains, as in the methyl-series, not less than five iodides. Among these the iodides of amylammonium and diamylammonium are present in the smallest quantity. The preparation of amylamine succeeds much better according to the process of M. Wurtz, namely, by submitting cyanate of amyl to the action of hydrate of potassa.

ACTION OF BROMIDE OF AMYL UPON AMYLAMINE.

Diamylamine.

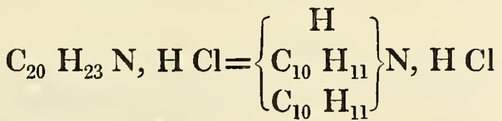
The formation of diamylamine takes place even in the cold, although slowly. At the temperature of boiling water, a mixture of amylamine and bromide of amyl is rapidly converted into a beautiful white crystalline mass of hydrobromate of diamylamine, which is purified, and decomposed in the usual manner. When purified, diamylamine is a light oily substance, very little soluble in water, to which it imparts, however, an alkaline reaction. Its aromatic odour is peculiar, not unpleasant, and reminds us of amylamine; its taste hot and pungent; it boils at about 170°. From want of pure material, the boiling-point could not be determined with accuracy.

Diamylamine forms very beautiful crystalline salts with the acids, which are all rather insoluble in water. The hydrochlorate is almost insoluble in cold water, but may be recrystallized from boiling water. This solution yields with bichloride of platinum a double salt, which is rather soluble, and separates frequently, in the first instance, in the form of oily drops, which become gradually crystalline.

It was by the analysis of these two salts that the composition of diamylamine was fixed.

0·2545 grm. of hydrochlorate gave 0·1852 grm. of chloride of silver.

The formula



$$C_{20}\,H_{23}\,N,\,H\,Cl = \left\{\begin{matrix} H \\ C_{10}\,H_{11} \\ C_{10}\,H_{11} \end{matrix}\right\} N,\,H\,Cl$$

requires the following values:—

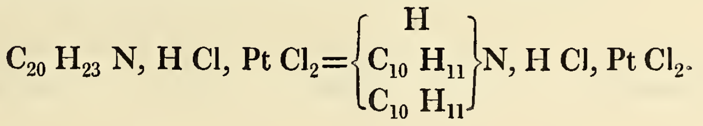
	Theory.		Experiment.
1 equiv. of Diamylamine	157·0	81·14	——
1 equiv. of Hydrochloric Acid	36·5	18·86	18·51
1 equiv. of Hydrochlorate of Diamylamine .	193·5	100·00	

These numbers show that the hydrochlorate employed was not perfectly pure; however, the two following platinum-salts leave no doubt respecting the base under examination.

I. 0·1634 grm. of platinum-salt gave 0·0444 grm. of platinum.
II. 0·1805 grm. of platinum-salt gave 0·0488 grm. of platinum.

	Percentage.	
	I.	II.
Platinum	27·17	27·04

The following theoretical values correspond to the formula



$$C_{20}\,H_{23}\,N,\,H\,Cl,\,Pt\,Cl_2 = \left\{\begin{matrix} H \\ C_{10}\,H_{11} \\ C_{10}\,H_{11} \end{matrix}\right\} N,\,H\,Cl,\,Pt\,Cl_2.$$

	Theory.		Experiment.
1 equiv. of Hydrochlorate of Diamylamine .	193·50	53·29	——
2 equivs. of Chlorine	71·00	19·54	——
1 equiv. of Platinum	98·68	27·17	27·10
1 equiv. of Platinum-salt	363·18	100·00	

ACTION OF BROMIDE OF AMYL UPON DIAMYLAMINE.

Triamylamine.

This base arises from diamylamine in the same manner as the latter from amylamine. It is moreover obtained, and at once in a state of purity, by exposing oxide of tetramylammonium, which I shall describe presently, to a high temperature; prepared by either way, this substance resembles in most of its physical and chemical characters diamylamine; it boils however at a much higher temperature, namely, at 257°. Its composition was fixed as that of diamylamine, by the analysis of the hydrochlorate and of the platinum-salt, the former being a very characteristic salt, which separates at once in nacreous plates on adding hydrochloric acid to the base, the latter being a viscid salt gradually solidifying to a crystalline mass.

0·1022 grm. of the hydrochlorate gave 0·0551 grm. of chloride of silver.

The formula

$$C_{30}\,H_{33}\,N,\,H\,Cl = \left.\begin{matrix} C_{10}\,H_{11} \\ C_{10}\,H_{11} \\ C_{10}\,H_{11} \end{matrix}\right\}\!\!\left.\vphantom{\begin{matrix}a\\a\\a\end{matrix}}\right\} N,\,H\,Cl$$

requires the following values:—

	Theory.		Experiment.
1 equiv. of Triamylamine	227·00	86·15	——
1 equiv. of Hydrochloric Acid	36·50	13·85	13·73
1 equiv. of Hydrochlorate of Triamylamine .	263·50	100·00	

The following platinum-determinations were made with three different salts: I, and II. were prepared with triamylamine, obtained by the action of bromide of amyl upon diamylamine; salt III. was made with the base resulting from the decomposition of oxide of tetramylammonium.

I. 0·3270 grm. of platinum-salt gave 0·0750 grm. of platinum.
II. 0·2182 grm. of platinum-salt gave 0·0500 grm. of platinum.
III. 0·3795 grm. of platinum-salt gave 0·0860 grm. of platinum.

	Percentage.		
	I.	II.	III.
Platinum	22·90	22·91	22·66

The theoretical values of the formula

$$C_{30}\,H_{33}\,N,\,H\,Cl,\,Pt\,Cl_2=\left.\begin{matrix}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{matrix}\right\}N,\,H\,Cl,\,Pt\,Cl_2$$

are as follows:—

	Theory.		Experiment.
1 equiv. of Hydrochlorate of Triamylamine	263·50	60·82	——
2 equivs. of Chlorine	71·00	16·40	——
1 equiv. of Platinum	98·68	22·78	22·82
1 equiv. of Platinum-salt	433·18	100·00	

ACTION OF IODIDE OF AMYL UPON AMYLAMINE AND UPON AMMONIA.

Oxide of Tetramylammonium.

A mixture of triamylamine and iodide of amyl solidifies after two or three days' ebullition to a solid, somewhat fat-like mass of iodide of tetramylammonium. A similar effect is produced by boiling an excess of iodide of amyl with a concentrated solution of ammonia. This reaction, however, takes place very slowly; in fact, the diminution of affinities characterizing the amyl-compounds in general was in none of these cases more marked. After two or three days' ebullition the volume of the ether appeared scarcely diminished; but then a gradual change occurred, the heavy amyl-compound rising and floating upon the solution of the new iodide which was formed. After a fortnight's ebullition the aqueous layer began to solidify, when allowed to cool; but even after keeping the mixture for a period of three weeks in ebullition, on opening the boiler-tube the reaction was found to be far from complete.

The semi-solid mixture thus obtained was subjected to distillation, first alone, in order to recover the iodide of amyl not acted upon; then with potassa, to separate ammonia and the lower amyl-bases. The alkaline liquid contained a small quantity of iodide of tetramylammonium in solution, which crystallized on cooling in fat-like leaves; the larger quantity, however, of this substance collected at the bottom of the vessel in form of a heavy oil, which solidified on cooling to a hard mass of the appearance of stearin.

The new iodide resembles in its general properties the corresponding compounds I have previously described. Like them it is soluble, but only with difficulty, in water, forming a most intensely bitter liquid, and reprecipitated from this solution in the crystalline form by the addition of the alkalies. On drying, the iodide assumes a slightly yellowish tint.

0·3890 grm. of the iodide gave 0·2130 grm. of iodide of silver.

The theoretical values of the formula

$$C_{40}\,H_{44}\,N\,I=\left\{\begin{array}{l}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{array}\right\}N\,I$$

are as follows:—

	Theory.		Experment.
1 equiv. of Tetramylammonium . . .	298·0	70·11	——
1 equiv. of Iodine	127·1	29·89	29·60
1 equiv. of Iodide	425·1	100·00	

On boiling the iodide with protoxide of silver, an alkaline, very bitter solution of the oxide of tetramylammonium is obtained. This substance is evidently far less soluble in water than the corresponding bases in the methyl- and ethyl-series. It would almost appear as if this compound stood to the methyl- and ethyl-bases as an alkaline earth does to potassa and soda.

On adding potassa to a solution of oxide of tetramylammonium, the base rises in the form of an oily layer on the surface of the liquid. The same separation is observed when the solution is much evaporated; in the latter case the oily layer gradually solidifies. On allowing a moderately concentrated solution of this base to stand for some time in a vessel in which it is protected from carbonic acid, magnificent perfectly definite crystals, sometimes an inch in length and in thickness, are deposited; they are but moderately deliquescent, and attract but slowly carbonic acid from the air. These crystals are the hydrate of tetramylammonium, containing a certain amount of water of crystallization. I have not yet been able to determine the number of equivalents. On heating these crystals, they fuse in their water of crystallization, and yield on evaporation in the water-bath a viscid semi-solid transparent mass, which is the hydrated oxide of tetramylammonium,

$$\left.\begin{array}{l}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{array}\right\}N\,O,\,HO.$$

This substance is extremely deliquescent, and opposes to an ordinary analysis the same obstacles which I met with in the case of tetrethylammonium. I succeeded, however, in the following manner, in determining with tolerable accuracy the composition of this mass. Having observed that this oxide is far less easily decomposed by heat than the corresponding ethyl-compound, I endeavoured to determine the state of hydration in which the oxide remained, by decomposing a known quantity of the iodide with protoxide of silver, and evaporating the solution thus obtained in a glass vessel, through which a current of air previously dried and decarbonated by potassa was passed at the temperature of boiling water. On weighing the residue, the amount of water retained by the oxide was given. The results obtained in this way, although not perfectly accurate on account of the oxide yielding a small quantity of triamylamine even at 100°, before the last traces of water of crystallization are expelled, nevertheless leave but little doubt respecting the nature of the residue. In an experiment of this kind

1·0610 grm. of iodide of tetramylammonium left 0·8000 grm. of residue.

This corresponds to 75·43 per cent.; if the viscid residue had been the pure monohydrated oxide I should have found 74·10 per cent.

I hope to repeat this experiment at a lower temperature, and also to determine the amount of water of crystallization in the crystallized compound; the latter is soon reproduced on adding again a moderate quantity of water to the viscid hydrate.

I have just now mentioned that the oxide, when heated in the water-bath, yields a small quantity of triamylamine. At a higher temperature this reaction proceeds with perfect regularity; an inflammable carbohydrogen being disengaged, together with the base. There can be scarcely any doubt that the former is amylene. This substance boils at a rather low temperature, 39°, and was therefore partly collected as gas. Another portion however dissolved in the triamylamine, from which it was expelled by ebullition after the base had been fixed by addition of hydrochloric acid. The analysis of the triamylamine obtained in this reaction has been mentioned at page 386. Hence the decomposition of oxide of tetramylammonium is perfectly analogous to that of its analogues in the ethyl-series, and is represented by the equation

$$\left.\begin{array}{l}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{array}\right\}NO,\ HO=2HO+\left\{\begin{array}{l}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{array}\right\}N+C_{10}\,H_{10}.$$

Oxide of tetramylammonium is distinguished by forming crystalline salts of remarkable beauty. The sulphate crystallizes in long hair-like filaments, the nitrate in needles, the oxalate in splendid large perfectly defined plates, of a very bitter taste, and extremely deliquescent. The chloride crystallizes in leaves with palm-like ramifications; it is likewise deliquescent, but less so than the preceding salt. The solution of the chloride yields with bichloride of platinum a pale-yellow curdy precipitate, which gradually solidifies into beautiful orange-yellow needles.

On analysis the following results were obtained:—

0·2420 grm. of platinum-salt gave 0·0475 grm. of platinum.

The theoretical numbers of the formula

$$C_{40}\,H_{44}\,N\,Cl,\ Pt\,Cl_2=\left\{\begin{array}{l}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{array}\right\}N\,Cl,\ Pt\,Cl_2$$

are as follows:—

	Theory.		Experiment.
1 equiv. of Tetramylammonium . . .	298·0	59·21	——
3 equivs. of Chlorine	106·5	21·19	——
1 equiv. of Platinum	98·68	19·60	19·63
1 equiv. of Platinum-salt	503·18	100·00	

The analysis of the tetramylammonium-salt concludes the experimental part of this paper; and here I cannot but make mention publicly of the valuable assistance which Mr. James S. Brazier, Senior Assistant in the Royal College of Chemistry, has given me during the prosecution of these inquiries. I thankfully acknowledge the aid of this able young chemist, whose experimental skill is equalled by his love of science.

Before passing on to some general considerations, which the experiments detailed in the preceding paper suggest, it appears to be desirable to condense the whole of the materials into a synoptical form. The appended Table requires no commentary; it contains the formulæ of the alkaloids described in this and the preceding memoir, exhibiting in a clear light the arrangement of the molecules composing them, and the manner in which the various compounds are interchained.

Ammonia (Amine) $\left\{\begin{matrix}H\\H\\H\end{matrix}\right\}N.$	Aniline (Phenylamine)	$\left\{\begin{matrix}H\\H\\C_{12}\,H_5\end{matrix}\right\}N.$	Ethylaniline (Ethylophenylamine)	$\left\{\begin{matrix}H\\C_4\,H_5\\C_{12}\,H_5\end{matrix}\right\}N.$	Diethylaniline (Diethylophenylamine)	$\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_{12}\,H_5\end{matrix}\right\}N.$	Oxide of Triethylophenyl-ammonium	$\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_4\,H_5\\C_{12}\,H_5\end{matrix}\right\}NO, HO.$
			Methylaniline (Methylophenylamine)	$\left\{\begin{matrix}H\\C_2\,H_3\\C_{12}\,H_5\end{matrix}\right\}N.$	Methylethylaniline (Methylethylophenylamine)	$\left\{\begin{matrix}C_2\,H_3\\C_4\,H_5\\C_{12}\,H_5\end{matrix}\right\}N.$		
			Amylaniline (Amylophenylamine)	$\left\{\begin{matrix}H\\C_{10}\,H_{11}\\C_{12}\,H_5\end{matrix}\right\}N.$	Diamylaniline (Diamylophenylamine)	$\left\{\begin{matrix}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{12}\,H_5\end{matrix}\right\}N.$		
					Ethylamylaniline (Ethylamylophenylamine)	$\left\{\begin{matrix}C_4\,H_5\\C_{10}\,H_{11}\\C_{12}\,H_5\end{matrix}\right\}N.$		
					Methylamylaniline (Methylamylophenylamine)	$\left\{\begin{matrix}C_2\,H_3\\C_{10}\,H_{11}\\C_{12}\,H_5\end{matrix}\right\}N.$	Oxide of Methylethyl-amylophenylammonium	$\left\{\begin{matrix}C_2\,H_3\\C_4\,H_5\\C_{10}\,H_{11}\\C_{12}\,H_5\end{matrix}\right\}NO, HO.$
	Chloraniline (Chlorophenylamine)	$\left\{\begin{matrix}H\\H\\C_{12}\binom{H_4}{Cl}\end{matrix}\right\}N.$	Ethylochloraniline (Ethylochlorophenylamine)	$\left\{\begin{matrix}H\\C_4\,H_5\\C_{12}\binom{H_4}{Cl}\end{matrix}\right\}N.$	Diethylochloraniline (Diethylochlorophenylamine)	$\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_{12}\binom{H_4}{Cl}\end{matrix}\right\}N.$		
	Bromaniline (Bromophenylamine)	$\left\{\begin{matrix}H\\H\\C_{12}\binom{H_4}{Br}\end{matrix}\right\}N.$	Ethylobromaniline (Ethylobromophenylamine)	$\left\{\begin{matrix}H\\C_4\,H_5\\C_{12}\binom{H_4}{Br}\end{matrix}\right\}N.$				
	Nitraniline (Nitrophenylamine)	$\left\{\begin{matrix}H\\H\\C_{12}\binom{H_4}{NO_4}\end{matrix}\right\}N.$	Ethylonitraniline (Ethylonitrophenylamine)	$\left\{\begin{matrix}H\\C_4\,H_5\\C_{12}\binom{H_4}{NO_4}\end{matrix}\right\}N.$				
	Ethylamine (Ethylammonia)	$\left\{\begin{matrix}H\\H\\C_4\,H_5\end{matrix}\right\}N.$	Diethylamine (Diethylammonia)	$\left\{\begin{matrix}H\\C_4\,H_5\\C_4\,H_5\end{matrix}\right\}N.$	Triethylamine (Triethylammonia)	$\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_4\,H_5\end{matrix}\right\}N.$	Oxide of Tetrethylammonium	$\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_4\,H_5\\C_4\,H_5\end{matrix}\right\}NO, HO.$
					Diethylamylamine (Diethylamylammonia)	$\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_{10}\,H_{11}\end{matrix}\right\}N.$	Oxide of Triethylamylammonium	$\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_4\,H_5\\C_{10}\,H_{11}\end{matrix}\right\}NO, HO.$
							Oxide of Triethylomethyl-ammonium	$\left\{\begin{matrix}C_4\,H_5\\C_4\,H_5\\C_4\,H_5\\C_2\,H_3\end{matrix}\right\}NO, HO.$
					Methylethylamylamine (Methylethylamylammonia)	$\left\{\begin{matrix}C_2\,H_3\\C_4\,H_5\\C_{10}\,H_{11}\end{matrix}\right\}N.$	Oxide of Diethylomethyl-amylammonium	$\left\{\begin{matrix}C_2\,H_3\\C_4\,H_5\\C_4\,H_5\\C_{10}\,H_{11}\end{matrix}\right\}NO, HO.$
	Methylamine (Methylammonia)	$\left\{\begin{matrix}H\\H\\C_2\,H_3\end{matrix}\right\}N.$	Dimethylamine (Dimethylammonia)	$\left\{\begin{matrix}H\\C_2\,H_3\\C_2\,H_3\end{matrix}\right\}N.$	Trimethylamine (Trimethylammonia)	$\left\{\begin{matrix}C_2\,H_3\\C_2\,H_3\\C_2\,H_3\end{matrix}\right\}N.$	Oxide of Tetramethylammonium	$\left\{\begin{matrix}C_2\,H_3\\C_2\,H_3\\C_2\,H_3\\C_2\,H_3\end{matrix}\right\}NO, HO.$
	Amylamine (Amylammonia)	$\left\{\begin{matrix}H\\H\\C_{10}\,H_{11}\end{matrix}\right\}N.$	Diamylamine (Diamylammonia)	$\left\{\begin{matrix}H\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{matrix}\right\}N.$	Triamylamine (Triamylammonia)	$\left\{\begin{matrix}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{matrix}\right\}N.$	Oxide of Tetramylammonium	$\left\{\begin{matrix}C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\\C_{10}\,H_{11}\end{matrix}\right\}NO, HO.$

The preceding researches show that the action of the bromides and iodides of the alcohol-radicals upon ammonia, gives rise to the formation of not less than four distinct groups of organic bases. Of these, the members of three groups, corresponding to ammonia ($H_3\,N$), are volatile, while those of the fourth, corresponding to oxide of ammonium ($H_4\,N\,O$), cannot be volatilized without decomposition. The facility with which the members of this last class arise from those of the preceding ones, and the readiness with which their reconversion is effected, renders the former group as it were the connecting link between the volatile and the non-volatile organic alkaloids. I am inclined to attach some importance to the latter point; for the acquisition of a general method, by means of which we may rise from the volatile to the non-volatile bases, is not unlikely to pave the way to the artificial production of the fixed native alkaloids, whose constitution is still shrouded in darkness. We may here remember that a very considerable number of these *fixed* native alkaloids yield *volatile* organic bases when submitted to the action of heat or of potassa,—that is under precisely those conditions under which the new ammonium-compounds, which I have described in this paper, are converted into conjugate ammonias. Thus quinine, cinchonine, strychnine, and pelosine yield among their products of decomposition leucoline (chinoline), while piperine gives picoline (?), and morphine, caffeine, codeine and narcotine have actually been converted into alcohol-bases, the former yielding methylamine, the latter two propylamine*.

I readily admit that those processes are by no means so simple as the passage of oxide of tetrethylammonium into triethylamine, several processes of transformation being in most of these cases accomplished side by side. A certain analogy, however, cannot possibly be denied, although, on account of the more complicated formulæ of the native bases, it cannot as yet be traced in simple equations. In some instances the connection even now appears almost palpable. If we compare the formulæ of quinine and of leucoline, the volatile base derived from its destruction, we are surprised to find that these substances exhibit the same elementary difference which we observe between oxide of tetramethylammonium and methylamine.

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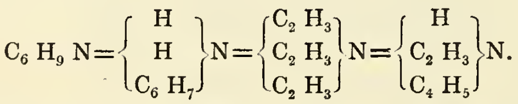
* M. Wertheim, the discoverer of this base, believes that it stands to the unknown propyl-alcohol in the same relation which exists between methylamine, ethylamine and amylamine on the one hand, and methylic, ethylic and amylic alcohol on the other. It deserves, however, to be noticed that the formula $C_6\,H_9\,N$ for this compound, as determined by experiment, expresses not only propylamine but also trimethylamine and even methylethylamine,



$$C_6\,H_9\,N=\left.\begin{cases} H \\ H \\ C_6\,H_7 \end{cases}\right\}N=\left.\begin{cases} C_2\,H_3 \\ C_2\,H_3 \\ C_2\,H_3 \end{cases}\right\}N=\left.\begin{cases} H \\ C_2\,H_3 \\ C_4\,H_5 \end{cases}\right\}N.$$

In the absence of decisive reactions, it remains doubtful which of these formulæ represents the base obtained by the action of soda-lime on narcotine; I may state here that propylamine, as prepared by Wertheim's process, and the liquid containing trimethylamine, for as yet I have not obtained this substance perfectly pure, exhibit the same remarkable fishy odour. It deserves moreover to be remarked that Dr. Anderson found that propylamine occurs, associated with methylamine, among the basic products of the decomposition of codeine.

$$\underbrace{C_{20}\,H_{12}\,N\,O_2}_{\text{Quinine.}} - C_2\,H_4\,O_2 = \underbrace{C_{18}\,H_8\,N}_{\text{Leucoline.}}$$

$$\underbrace{C_8\,H_{13}\,N\,O_2}_{\substack{\text{Hydrated oxide}\\ \text{of Tetramethyl-}\\ \text{ammonium.}}} - C_2\,H_4\,O_2 = \underbrace{C_6\,H_9\,N}_{\substack{\text{Trimethyl-}\\ \text{amine.}}}$$

Accordingly, we might expect that the action of iodide of methyl upon leucoline, and the subsequent decomposition of the iodide produced by means of protoxide of silver, would enable us to reconvert leucoline in this manner into quinine. This metamorphosis would be the more interesting, as it would open a source for the artificial production of quinine; leucoline being, as is well known, contained in considerable quantity in the basic portion of coal-tar naphtha. It may be stated here that leucoline, which is a substance remarkable for its antipathy to the crystalline form, when submitted to the action of iodide of methyl, solidifies at once into a splendid mass of crystals of a new iodide*, which in fact resembles in its outward appearance hydriodate of quinine, and which is still under examination. I am, however, by no means sanguine as to the result of this experiment, for the above play of formulæ rests as yet on a very precarious foundation; neither the formula of quinine nor that of leucoline being established beyond a doubt. Nevertheless, I intend to complete this investigation, because even if no other result is obtained, yet by means of this process new data for ultimately fixing the formulæ of quinine and leucoline may be found.

In conclusion, it may not be out of place to consider how far the preceding researches affect the received views regarding the constitution of the ammonia-salts. Without reproducing all the arguments brought forward by the supporters of the various theories, we may remember that, irrespectively of the impossibility of isolating ammonium itself, the instability of its oxide has been adduced as one of the most important objections against the assumption of the ammonium-theory as originally suggested by Ampère, and subsequently elaborated by Berzelius. It deserves to be noticed that Berzelius expressly states that he considers the solution of ammonia-gas in water as a solution of the hydrated oxide of ammonium.

This idea, which is but a logical conclusion from the generalization of the facts, is discountenanced to a certain extent by the chemical and physical character of this solution. Everybody knows that, even at the common temperature, this liquid splits again into water and ammonia, while it still exhibits the character of the latter in so marked a manner, as almost to preclude the idea that it had undergone as essential a change as the transformation into oxide of ammonium necessarily must be. Under these circumstances, some interest is attached to the discovery of a series of compound bases, corresponding in their composition to hydrated oxide of ammonium, from which they differ only by containing methyl, ethyl and amyl in the place of hydrogen, and exhibiting a deportment which agrees much better with the anticipated character of such compounds as suggested by analogy. Here we find a very marked difference between the properties of the compound ammonia, and those of the ammonium-oxide belonging to it; in the latter, we observe no longer any feature which could possibly betray the presence of the former; all their habits, volatility, odour, taste, &c. are totally changed; there is a difference between the two groups which is not inferior to that between ammonia and potassa. The solutions of the new oxides may be boiled for hours without the slightest quantity of the corresponding ammonia being disengaged; several of these oxides, containing more or less water of constitution or crystallization, may actually be obtained in the dry state. It is evident that the arguments mentioned above, as adduced in refutation of the ammonium-theory, cannot well be raised against the compound ammoniums. But who could deny the parallelism of these substances with the Berzelian type,—with the oxide of ammonium?

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* A similar result is obtained by the action of iodide of ethyl upon conine and nicotine.

Again, many have found it difficult to conceive, that in the combination of ammonia with hydrochloric or hydrobromic acid, the hydrogen of the latter should leave the chlorine and bromine, for which it is known to possess so powerful an affinity, in order to unite with ammonia converting it into ammonium. And they were the less inclined to admit of such a disposition of the elements, as every day's experience showed that the alleged chloride or bromide of ammonium was incapable of exchanging oxygen for chlorine or bromine, without losing the additional equivalent of hydrogen again in the form of water. In other terms, the decomposition of sal-ammoniac, by lime, into chloride of calcium, ammonia-gas and water, induced them to consider this salt as a compound of ammonia and hydrochloric acid; for in the conception of the ammonium-theory we should have to assume in this decomposition *two* consecutive changes, the transformation of the chloride into oxide, and the subsequent splitting of the latter into ammoniacal gas and water. I readily admit that the latter view is less simple, but I am inclined to think that this slight inconvenience is altogether overruled by the general advantages of the ammonium-theory, especially for the purposes of instruction, by the facility with which it accounts for all phenomena of transposition and substitution, and by the simple explanation it gives of the isomorphism of the potassium- and ammonium-compounds, which will always be the firmest foundation of this theory. On the other hand, we have to inquire which of the two views comes nearest to truth, and here a comparative consideration of the deportment exhibited by the compound ammoniums may be of some interest. In many respects their properties are more clearly pronounced; and their behaviour is explicit and unequivocal in those very points in which the typical ammonium leaves room for speculation. In the combination of triethylamine with bromide or iodide of ethyl, it is no longer a matter of doubt whether the ethyl leaves the iodine in order to unite more intimately with the triethylamine, for we see that the new iodide thus produced is capable of exchanging its iodine for oxygen without the newly-formed oxide suffering immediate decomposition, as is the case with oxide of ammonium. On the contrary, we find this new oxide endowed with remarkable stability; although under the influence of heat it is liable to the same change which befalls the oxide of ammonium, its corresponding ammonia being reproduced. Here then, in the decomposition of iodide of triethylammonium by metallic oxides, we are obliged by irresistible evidence to acknowledge those very two stages, the assumption of which in the analogous change of iodide of ammonium appeared to us deficient in simplicity and probability.

The conception of ammonium does not in any way imply the notion that the different hydrogen-atoms united with nitrogen in the molecule of the compound metal, retain their position in the molecular system with equal persistency. We are forced by unequivocal facts to admit that the fourth atom of hydrogen is in a peculiar state of mobility, and it is on the facility with which this fourth atom is dislodged from its position that one of the foundations of the ammonia-theory rests. In the compound ammoniums the mobility of the fourth atom of hydrogen, or the hydrocarbon replacing it, still prevails, although less so than in the type itself. The decomposition of the ammonium-bases under the influence of heat is particularly instructive in this respect; oxide of tetrethylammonium loses the fourth equivalent of ethyl in the form of olefiant gas and water; and this deportment might be graphically indicated by writing the formula of this compound in accordance with the ammonia-theory, namely, thus—

$$\left.\begin{matrix} C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \end{matrix}\right\} N,\ C_4\,H_5\,O.$$

The iodide accordingly would be represented by the formula

$$\left.\begin{matrix} C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \end{matrix}\right\} N,\ C_4\,H_5\,I,$$

an expression which is moreover in perfect harmony with the mode in which this compound is produced, namely, by the direct union of iodide of ethyl with triethylamine.

But now we combine the triethylamine with iodide of amyl, whereby the iodide

$$\left.\begin{matrix} C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \end{matrix}\right\} N,\ C_{10}\,H_{11}\,I$$

is formed, which, as we have seen in the preceding pages, may be converted without difficulty into the corresponding oxide; this oxide however cannot possibly be considered as

$$\left.\begin{matrix} C_4\,H_5 \\ C_4\,H_5 \\ C_4\,H_5 \end{matrix}\right\} N,\ C_{10}\,H_{11}\,O,$$

for the disengagement of olefiant gas under the influence of heat proves to us that it is an ethyl-atom which in this compound occupies the supplemental position, if I may so call it, as represented in the formula

$$\left.\begin{matrix}C_4\ H_5\\C_4\ H_5\\C_{10}\ H_{11}\end{matrix}\right\}N, C_4\ H_5\ O,$$

and that the iodide, which is not likely to differ in its constitution from the oxide, has likewise to be represented by the formula

$$\left.\begin{matrix}C_4\ H_5\\C_4\ H_5\\C_{10}\ H_{11}\end{matrix}\right\}N, C_4\ H_5\ I.$$

The preceding considerations clearly show, that, whatever the actual disposition of the molecules in ammonium or its congeners may be, the atoms re-arrange themselves whenever the fourth equivalent of hydrogen, or of its substitute, joins the compound.

This re-arrangement, so evident in the ammonium-bases, containing various hydrocarbons, may be traced moreover in the lower ethyl-bases in a very obvious manner. For as long as there is any basic hydrogen present in the ammonia-skeleton, this hydrogen assumes what I have previously called the supplemental position, whenever the ammonia passes into the state of ammonium by the accession of a radical. Bromide of ethylammonium formed by the combination of ammonia with bromide of ethyl, when decomposed by a metallic oxide, yields ethylammonia, water and a metallic bromide, the oxide of ethylammonium formed in the first instance being decomposed like oxide of ammonium itself. It is this very transposition which we are in the habit of representing by the equation

$$H_3\ N+C_4\ H_5\ Br=C_4\ H_5,\ H_2\ N, H\ Br.$$

In the preceding pages I have stated some of the reasons which induced me to adopt the idea of an ammonium for the new class of compounds which I have had the honour to place before the Royal Society in the present memoir. I need scarcely mention, that such a step involves as a matter of necessity the assumption of a similar view for all the lower bases which form part of this investigation. It would be inconsistent to speak any longer of hydrochlorate of ethylamine, of hydrobromate of diethylamine, &c.; these salts have henceforward to be called chloride of ethylammonium, bromide of diethylammonium, &c., these compounds being nothing but intermediate substitution-terms between the type and the last derivative. On considering the various chlorides from this point of view, we arrive at the following series:—

Chloride of Ammonium	H_4	N Cl.
Chloride of Ethylammonium	$\left\{\begin{matrix}H_3\\C_4\ H_5\end{matrix}\right\}$	N Cl.

Chloride of Diethylammonium . . . . $\left\{\begin{matrix}H_2\\(C_4\,H_5)_2\end{matrix}\right\}N\,Cl.$

Chloride of Triethylammonium . . . . $\left\{\begin{matrix}H\\(C_4\,H_5)_3\end{matrix}\right\}N\,Cl.$

Chloride of Tetrethylammonium . . . . $(C_4\,H_5)_4\;N\,Cl.$

The idea of an ammonium once adopted, we have to follow it out in as general a form as possible, and hence I perfectly agree with those chemists who consider the salts of Reiset's second base as compounds of the Platammonium (Platosammonium)

$$\left.\begin{matrix}H_3\\Pt\end{matrix}\right\}N\,X,$$

the ammoniosulphate of silver as sulphate of argentammonium,

$$\left.\begin{matrix}H_3\\Ag\end{matrix}\right\}N\,SO_4,$$

and the ammoniochloride of copper as chloride of cuprammonium,

$$\left.\begin{matrix}H_3\\Cu\end{matrix}\right\}N\,Cl.$$

But I would go farther and advocate an analogous constitution for a great number of mercury-compounds, which are now usually considered in a different way. Since the careful experiments of Sir Robert Kane have pointed out the true composition of the white precipitate, chemists are in the habit of viewing this substance as a compound of chloride and amide of mercury,

$$Hg\,H_2\,N,\;Hg\,Cl\,;$$

it may be viewed with equal justice as chloride of dimercurammonium,

$$\left.\begin{matrix}H_2\\Hg_2\end{matrix}\right\}N\,Cl,$$

and would correspond in this form to the chloride of diethylammonium; dimercurammonium, intimately combined with protoxide of mercury, may be assumed in all the various salts of M. Millon's mercury-base. It would be interesting experimentally to follow out in detail the analogy of the mercury-compounds with the series of ethyl bases. Even now the materials at our disposal appear to point to the existence of the other terms. In Mitscherlich's garnet-octohedrons we might perceive a chloride of mercurammonium,

$$\left.\begin{matrix}H_3\\Hg\end{matrix}\right\}N\,Cl,$$

while Plantamour's nitride of mercury presents itself as trimercuramine, $Hg_3\,N$; and the red compound obtained by Mitscherlich on heating the white precipitate, might be viewed as a combination of chloride of mercury with chloride of tetramercurammonium,

$$Hg_4\,N\,Cl,\;Hg\,Cl.$$

The ammonium type may be traced even in a class of compounds which has hitherto been regarded in a perfectly different point of view. I refer to the substances produced by the combination of metallic salts with more than one equivalent of ammonia. Protochloride of platinum unites with two equivalents of ammonia, forming the chloride of Reiset's first base; in the same manner, sulphate of copper, nitrate of silver, absorb both two equivalents of ammonia, the latter salt even three equivalents. These substances, although containing 2 equivs. of nitrogen, may still be viewed as ammonium-compounds, if we apply to them an interesting observation made by Professor Graham, namely, that ammonia, whenever it joins a compound containing hydrogen, may be regarded as ammonium replacing 1 equiv. of hydrogen. When viewed in this light, the substances above quoted would assume the following formulæ:—

Reiset's first chloride	$\left.\begin{matrix} H_2 \\ Pt \\ (H_4 N) \end{matrix}\right\} N\,Cl.$	Chloride of ammonio-platammonium.
Diammoniacal sulphate of copper . .	$\left.\begin{matrix} H_2 \\ Cu \\ (H_4 N)_2 \end{matrix}\right\} N\,SO_4$	Sulphanide of ammonio-cuprammonium.
Diammoniacal nitrate of silver . . .	$\left.\begin{matrix} H_2 \\ Ag \\ (H_4 N) \end{matrix}\right\} N\,NO_6$	Nitranide of ammonio-argentammonium.
Triammoniacal nitrate of silver . .	$\left.\begin{matrix} H \\ Ag \\ (H_4 N)_2 \end{matrix}\right\} N\,NO_6$	Nitranide of diammonio-argentammonium.

I readily admit that here speculation appears rather in advance of experiment. Nevertheless it deserves to be noticed, that among the substances produced by the action of ammonia upon metallic salts, of which so great a variety has been investigated by Henry Rose, there is, as far as I know, not a single one containing more than 4 equivs. of ammonia, which still admits of their being included in the idea to which I have alluded.

XV. *Contributions to Animal Chemistry.*—Paper V.

On the Oxidation of Ammonia in the Human Body, with some Remarks on Nitrification.

By HENRY BENCE JONES, *M.D., M.A. Cantab., F.R.S., Physician to St. George's Hospital.*

Received December 18, 1850,—Read January 30, 1851.

IN a paper lately communicated to the Royal Society, I showed that the effect of tartrate of ammonia on the acidity of the urine was totally different from that of tartrate of potash; and that carbonate of ammonia taken in very large quantities did not produce any alkaline reaction of the urine; on the contrary, the acidity was rather increased than diminished by large doses of carbonate of ammonia. I repeated these experiments with carbonate of ammonia, hoping to obtain more decided results; but I could not determine the fact of any great increase in the acidity of the urine, although it was again apparent that no diminution of the acid reaction resulted from taking carbonate of ammonia.

I also repeated these experiments on many patients in St. George's Hospital suffering from chronic rheumatism, but though some took on an average 50 grs. of carbonate of ammonia daily for seven or more weeks, yet no alkaline state of the urine could be produced.

In consequence of these observations, I suggested in my paper that an inquiry into the occurrence of nitric acid in the urine would probably give the solution of this unexpected effect of carbonate of ammonia.

Hitherto but few observations have been made on the occurrence of nitric acid in the urine in health or disease. Dr. PROUT, in the Medico-Chirurgical Transactions, vol. ix. p. 481, mentions that he found nitric acid in the pink sediment from the urine of those labouring under febrile and inflammatory diseases, but he says nothing of the urine containing it in solution; hence, possibly, it came from the baryta used in the process of testing the sediment. WURTZER also obtained nitric acid; LEHMANN thinks, that in this case also it came from the impure baryta.

Thus, then, regarding the presence of nitric or nitrous acids in the urine our knowledge is deficient. Moreover, the difficulty of recognizing very small quantities of nitric acid is considerable, and the accurate determination of the quantity present in organic liquids is almost impossible.

Through the kindness of Mr. FARADAY I was allowed the use of the laboratory at the Royal Institution, and I obtained the assistance of Dr. PRICE to conduct my experiments without interruption.

The delicacy of the different tests for nitric acid was first ascertained, and then a series of experiments was made to determine what was the smallest amount of nitrate of potash that could be detected in the urine when nitre was dissolved in the water after it had passed out of the body.

The indigo test for nitric acid being more delicate than the protosulphate of iron test, it was chiefly employed. But far more delicate than either test was a mixture of starch with one drop or two of a solution of hydriodate of potash, specific gravity 1052, and very dilute hydrochloric acid, specific gravity 1005. This test Dr. Price suggested to me, and the precautions necessary in its use and its advantages he will more fully describe elsewhere. Depending on the production of a deep colour, and not on the removal of colour, it gave evidence when the indigo test afforded none; and if the quantity of iodide of potassium was very small, and if the hydrochloric acid was very dilute, comparative experiments showed that reliance could be placed upon this test.

In the examination of the urine the method was this. From four to eight ounces were taken, and if a larger quantity was passed, it was evaporated to about this quantity in a water-bath, and then mixed with half an ounce of strong and pure sulphuric acid, perfectly free from every trace of nitric acid. Distillation was carried on in a retort until at least two thirds of the fluid had passed into the receiver, when the distillate was neutralized with pure carbonate of potash and evaporated to a very small bulk. From a drop to half the residue was added to the mixture of starch, hydriodate of potash and dilute hydrochloric acid. Another portion was placed in a bason; a very small quantity of indigo was added with an excess of sulphuric acid, and heat was applied for some minutes. The greenish colour of the indigo with the residue of the distillate arose from a small quantity of yellow colouring matter which came over in the distillation and grew darker by evaporation. If too much indigo was used, slight traces of nitric acid could not be detected. Occasionally the protosulphate of iron was also used as a test.

Beginning at first with 10 grs. of nitrate of potash added to 10 ounces of urine, it was found at last that as little as 1 gr. of nitrate to 10 ounces of urine could be detected by this process when the starch test was used, with the greatest certainty and clearness. This quantity could not be detected as surely by the indigo and sulphuric acid test.

Healthy urine was first examined to see if it contained nitric acid.

(1.) One hundred and twenty ounces, the produce of five persons, were evaporated to a small bulk; on distillation with sulphuric acid no nitric acid could be found.

(2.) Thirty ounces, the produce of two other persons, were examined, and no nitric acid was found.

(3.) Twenty ounces of urine, passed by a healthy man, were concentrated and distilled, but no nitric acid was found.

The same person was then made the subject of the following experiments:—

Experiments with Carbonate of Ammonia.

Breakfast was usually taken at 8 o'clock and dinner at 6 o'clock. Both meals consisted of mixed diet; cocoa was taken at breakfast, and water only at dinner.

(4.) At $11^h 40^m$ A.M. a single dose of 40 grs. of carbonate of ammonia was taken dissolved in 8 ounces of distilled water.

At 3 P.M. 8 ounces of urine were passed, which gave very decided evidence of nitric acid by the indigo test and by the starch test.

At 6 P.M. 15 ounces of water: no result was obtained in consequence of an accident.

At 11 P.M. 9 ounces. By the indigo test no nitric acid was found. By the starch test a slight trace of nitric acid was detectable.

At $7^h 25^m$ A.M. 14 ounces. Gave no evidence of nitric acid by either test.

Up to $7^h 25^m$ A.M. the following day 41 ounces of urine were passed. In this large quantity the indigo test gave no nitric acid; but the starch test still showed slight evidence of the presence of the acid.

Thus then after 40 grs. of carbonate of ammonia, nitric acid could be detected in the urine made three hours after the ammonia was taken. After twelve hours a trace was perceptible, and after twenty hours it had not altogether disappeared.

(5.) This experiment was again repeated on the same person.

At $7^h 20^m$ A.M. 16 ounces of urine were passed; on examination no trace of nitric acid could be detected by the indigo or starch tests. 40 grs. of carbonate of ammonia were taken, dissolved in distilled water; very active exercise followed for nearly an hour after the volatile alkali was taken.

At $8^h 40^m$ A.M. 4 ounces of urine were passed, and breakfast was then taken; nitric acid was found to be present in considerable quantity, both by the indigo and starch tests.

At $12^h 30^m$ A.M. 7 ounces of urine gave no proof of nitric acid by the indigo test, but distinct evidence by the starch test.

At $3^h 30^m$ P.M. 5 ounces. Gave no proof by indigo; less evident by the starch test.

At 11 P.M. 12 ounces. Gave no evidence of nitric acid by either test.

In this experiment, previous to any food being taken, nitric acid was found in the urine after a dose of carbonate of ammonia; although before the carbonate of ammonia was taken no nitric acid could be detected in four times the quantity of urine.

For eight hours the nitric acid was detectable by the starch test.

(6.) The same experiment was again repeated, but instead of active exercise there was perfect rest, after taking the carbonate of ammonia.

At $6^h 45^m$ A.M. 15 ounces, in which no trace of nitric acid could be detected by the indigo or starch test. At this hour 40 grs. of carbonate of ammonia were taken in distilled water.

At 8^h 15 A.M. 5 ounces passed. The indigo test gave no proof of nitric acid; the starch test showed the presence of a small quantity.

At 11^{h} 45^{m} A.M. $5\frac{1}{2}$ ounces. Both the indigo and starch test gave proof of nitric acid.

At 2^{h} 45^{m} P.M. 4 ounces, in which nitric acid was proved to be present by both tests.

At 6^{h} 10^{m} P.M. $6\frac{1}{2}$ ounces. The indigo test gave no proof. The starch test gave it readily.

At 12^{h} 25^{m} P.M. 10 ounces. Still the starch test showed a trace of nitric acid.

At 7^{h} 40^{m} A.M. 14 ounces. Still the slightest trace by starch test.

Comparing this with the previous experiment, it appears that exercise after the carbonate of ammonia causes the nitric acid to appear in the urine more quickly and to pass out more rapidly. With perfect rest, after twenty-four hours a trace of nitric acid was perceptible. With active exercise, after eight hours it ceased to be detected.

Further experiments were then made to determine what was the smallest quantity of carbonate of ammonia that could cause nitric acid to appear in the urine.

(7.) At 1 P.M. 20 grs. of carbonate of ammonia were taken in 6 ounces of distilled water. Moderate exercise was taken until 6 P.M., when 8 ounces of urine were passed. In this nitric acid was detected by the indigo and starch tests.

At 11 P.M. 7 ounces of urine gave nitric acid by both tests. Urine secreted from 10^{h} 30^{m} P.M. the following night to 7^{h} 30^{m} A.M. the next morning, about 24 ounces, gave no proof of nitric acid by the indigo test, but gave a trace with the starch test.

Still smaller quantities of carbonate of ammonia were taken.

(8.) At 12^{h} 30^{m} A.M. about 7 ounces gave no evidence of nitric acid by the indigo or starch test. At this time 5 grs. of carbonate of ammonia were taken in an ounce and a half of water.

At 5^{h} 55^{m} P.M. $7\frac{1}{2}$ ounces gave no proof of nitric acid by the indigo test; slight evidence by starch.

At 12^{h} 10^{m} P.M. 15 ounces; slightest evidence by starch.

At 7^{h} 40^{m} A.M. 15 ounces; the same.

(9.) At 12^{h} 20^{m} A.M. 12 ounces; doubtful evidence of nitric acid. At this hour 10 grs. of carbonate of ammonia were taken in $2\frac{1}{2}$ ounces of distilled water.

At 6^{h} 50^{m} P.M. 9 ounces; gave proof of nitric acid by the indigo and starch tests.

At 12^{h} 20^{m} P.M. 15 ounces; indigo gave no proof; starch decided proof.

At 7^{h} 30^{m} A.M. 17 ounces; no decided evidence.

Hence it appears that 10 grs. of carbonate of ammonia was the smallest quantity that gave decided evidence of nitric acid by both tests. In the course of ten days, in all, 155 grs. of carbonate of ammonia were taken.

(10.) After this quantity of carbonate of ammonia, the water passed at 7^{h} 30^{m} A.M., as I have said, gave no decided evidence.

At 12^{h} 25^{m} A.M. 12 ounces of urine gave decided evidence with starch; none with indigo.

At $11^h\ 50^m$ P.M. 19 ounces; still evidence of nitric acid with the starch test.

(11.) At $12^h\ 20^m$ A.M. 17 ounces. No evidence of nitric acid; and for the five next days the total quantity of urine passed was collected and examined, and each day the slightest evidence of nitric acid was obtained by the starch test. The examination was continued for the four next days; each day the whole quantity passed was evaporated and distilled, but not a trace of nitric acid could be detected.

Thus seven days after the carbonate of ammonia was omitted still traces of nitric acid could be detected in the urine, if large quantities were evaporated and examined.

In order to be more certain regarding the effect of single doses of carbonate of ammonia, the urine of two children, the one aged seven, the other six, was examined. The total quantity passed by both in the day was 40 ounces. It was evaporated and examined, but no nitric acid could be detected by the indigo or starch tests.

(12.) The child aged seven took 5 grs. of carbonate of ammonia at 11 A.M. The urine passed during the evening and the following morning was in quantity 13 ounces. It was acid, and gave no evidence of nitric acid.

The same child took rather less than 10 grs. of carbonate of ammonia.

(13.) At 8 A.M. the urine made during the day up to the following morning, in quantity 16 ounces, contained a trace only of nitric acid by the starch test.

(14.) The other child, aged six, took rather less than 10 grs. of carbonate of ammonia.

At 8 A.M. the urine first passed after this dose was lost by an accident. The water passed from 5 P.M. to 7 A.M., in quantity 10 ounces, gave no trace of nitric acid.

(15.) The experiment was repeated, 10 grs. of carbonate of ammonia were taken at 8 A.M.

At 6 P.M. about 10 ounces of urine gave nitric acid with the indigo test and with the starch test.

The water from 6 P.M. to the next day at 1 P.M. was lost, but in the water passed during the afternoon and night of the next day no nitric acid could be detected.

(16.) A patient in St. George's Hospital was given 7 grs. of carbonate of ammonia every four hours for rheumatism, after he had taken smaller quantities for three days previously. Twenty-four ounces of urine evaporated gave distinct evidence of nitric acid by the indigo and starch tests.

Experiments with Liquor Ammoniæ.

(17.) A patient was given for ten days small quantities of Liquor Ammoniæ, in all about half a drachm of the Pharmacopœia liquid; twelve ounces of urine evaporated gave evidence of nitric acid with the starch test, but none with the indigo.

Having thus satisfied myself that when carbonate of ammonia was taken small quantities of nitric acid passed off in the urine, I tried whether tartrate of ammonia would give the same result.

Experiments with Tartrate of Ammonia.

(18.) Breakfast and dinner were at the same hours as before.

Water passed from 7½ A.M. to 11½, in quantity 8 ounces, gave slight evidence of nitric acid by the starch test, none by the indigo.

At 11½ A.M. tartrate of ammonia, 60 grs., were taken in 4 ounces of distilled water.

At 3 P.M. 7 ounces of urine gave evidence of nitric acid by the indigo, iron, and starch tests.

At 6 P.M. 7 ounces gave nitric acid with the starch test, but not with the indigo.

At 12^h 30^m A.M. 10 ounces. Starch test gave evidence of nitric acid.

At 8^h 15^m A.M. 18 ounces. No evidence of nitric acid by either test.

(19.) Another day. Water at 6^h 45^m A.M. thrown away.

At 11^h 45^m A.M. about 8 ounces. Still gave a trace of nitric acid by the starch test. At this hour 40 grs. of tartrate of ammonia were taken in distilled water.

At 6^h 20^m P.M. 11 ounces of urine gave evidence of nitric acid with the starch test.

At 12^h 15^m P.M. 7 ounces. Nitric acid much more evidently.

At 7 A.M. 14 ounces. Still distinctly evident.

Up to 7^h 30^m A.M. the following morning, 54 ounces of water passed contained no trace of nitric acid.

(20.) A child, seven years old, took 20 grs. of tartrate of ammonia in some tea at 8 A.M. Urine secreted from this time to 6 A.M. the following day, in quantity 18 ounces, gave no trace of nitric acid.

As small quantities of nitric acid were detected in two of these experiments previous to the time when the tartrate of ammonia was taken, though the quantity of nitric acid was much increased afterwards, yet further experiments were made. Another healthy person took the same amount of tartrate of ammonia.

(21.) The urine made before the ammonia was taken contained no nitric acid.

At 12 A.M. 40 grs. of tartrate of ammonia were taken dissolved in 6 ounces of distilled water.

At 3 P.M. the urine was acid and contained a trace of nitric acid, by the starch test.

Up to 9 A.M., the following morning, the urine was collected, concentrated and distilled, but not the slightest trace of nitric acid was detected.

(22.) The experiment was repeated at 1 P.M.: 60 grs. of tartrate of ammonia were taken dissolved in 9 ounces of water. In three quarters of an hour it acted on the bowels. The water passed prior to the dose, in quantity 8½ ounces, was examined for nitric acid, but not a trace could be detected.

At 4^h 15^m urine highly acid, 6½ ounces. It gave a large quantity of nitric acid.

At 11 P.M. 6 ounces. Nitric acid found most readily.

At 8 A.M. nitric acid was not detected.

At 2^h 45^m P.M. 7 ounces. A considerable quantity of nitric acid was detected.

At 12 P.M. gave a trace of nitric acid.

Experiments with Muriate of Ammonia.

As in the first experiments on the same person, the dinner and breakfast were the same as before.

(23.) Water passed from 7h 30m A.M. to 11h 20 A.M. 7 ounces. When examined for nitric acid no trace was found.

At 11h 20m A.M. 120 grs. of muriate of ammonia were taken in 10 ounces of distilled water.

At 2h 40m P.M. 7½ ounces of water passed contained so much nitric acid that the distillate required no condensation to give immediate evidence by all the tests.

At 5h 50m P.M. 8 ounces. No trace of nitric acid was found.

At 11h 45m P.M. 8 ounces. No nitric acid was detected.

At 7h 35m A.M. 19 ounces. In this larger quantity a trace of nitric acid was found.

At 7h 35m A.M. the day following, 42 ounces. Contained no trace of nitric acid; to 7h 35m A.M. the day following, 38 ounces. The slightest trace of nitric acid was detected.

(24.) The same person took 10 grs. of muriate of ammonia.

The water passed from 7h 30m A.M. to 11h 10m A.M., in quantity 4 ounces, previous to the muriate of ammonia, contained scarcely a trace of nitric acid.

At 11h 10m A.M. 10 grs. of muriate of ammonia were taken in distilled water.

At 2h 30m P.M. 5 ounces of water contained so much nitric acid that it was detectable without evaporating the distillate.

At 6h 50m P.M. 5 ounces. The evaporated distillate gave nitric acid most readily.

In this experiment a trace of nitric acid was found in the urine passed previous to the taking of the muriate of ammonia. The occurrence of minute traces of nitric acid after breakfast was also observed in (9.), (18.), (19.) and (25.); from these observations it is not improbable that the nitric acid came from minute quantities of the salts of ammonia occasionally present in the food.

(25.) By another person, 25 grs. of muriate of ammonia were taken.

The urine made just previous to the medicine, was examined at midday; it contained a small quantity of nitric acid by the starch test, perhaps resulting from the tartrate of ammonia previously taken.

At 12 o'clock 25 grs. of muriate of ammonia were taken in water.

At 1h 30m P.M. a very considerable quantity of nitric acid was detected by all the tests.

At 4 P.M. nitric acid was detected without concentrating the distillate.

At 12 P.M. no nitric acid could be detected.

At 8 A.M. no nitric acid was found.

(26.) A child, six years old, was given 10 grs. of muriate of ammonia in tea, at breakfast. The urine made during the day, up to 6 o'clock the following morning, in quantity 20 ounces, contained only a small quantity of nitric acid by the starch test.

(27.) A child, seven years old, was given 5 grs. of muriate of ammonia in tea, at breakfast. The urine made during the day, and up to 8 o'clock the following morning, in quantity 16 ounces, contained a considerable quantity of nitric acid, by indigo, starch and protosulphate of iron tests.

Finding that salts of ammonia *in transitu* through the body gave rise to nitric acid, I made the following experiment to see whether out of the body nitric acid could be produced by the direct combustion of ammonia.

Ammoniacal gas was passed into alcohol. This ammoniacal alcohol, specific gravity about ·861, was burnt in a spirit-lamp: the products of combustion were passed through a dilute solution of carbonate of potash by means of an aspirator. In all about 3 ounces of alcohol were burnt, the combustion lasting one hour. The solution of carbonate of potash was tested for nitric acid, without being evaporated to a smaller bulk; and the presence of nitric acid was most distinctly proved by the starch test, by the indigo test, and by the protosulphate of iron test. Thus by simple combustion out of the body, as well as in the body, nitric acid was produced.

The close relation of urea to carbonate of ammonia immediately gave rise to the idea that possibly it also would be changed *in transitu.*

Experiments with Urea.

(28.) At $11^h\ 30^m$ A.M. 20 grs. of urea were taken in 3 ounces of distilled water.

At 6 P.M. the slightest trace of nitric acid was found by the starch test in 9 ounces of urine.

At $12^h\ 30^m$ P.M. about 9 ounces of urine gave no nitric acid.

At $7^h\ 30^m$ A.M. 11 ounces gave no trace of nitric acid.

(29.) The experiment was repeated with 40 grs. of urea.

The urine passed from $7^h\ 30^m$ to $11^h\ 45^m$ A.M. was about 5 ounces; it contained no trace of nitric acid.

At $11^h\ 45^m$ A.M. 40 grs. of urea were taken in 4 ounces of distilled water.

At 6 P.M. about 12 ounces of urine gave evidence of plenty of nitric acid by the indigo test and the starch test.

At 12 P.M. about 7 ounces. No proof of nitric acid.

At $7^h\ 30^m$ A.M. about 12 ounces. Gave no proof.

To $7^h\ 30^m$ A.M., the following morning, the urine in quantity 48 ounces, gave no trace of nitric acid.

(30.) These experiments were also made on another person.

At 12 A.M. 20 grs. of urea were taken dissolved in 5 ounces of water.

At $1^h\ 30^m$ P.M. 6 ounces of urine passed, acid to test-paper. Gave with the starch decided proof of nitric acid.

At 4 P.M. 3 ounces gave slighter proof of nitric acid.

To 9 A.M. the water when evaporated and distilled gave no evidence of nitric acid.

(31.) On another day 40 grs. of urea were taken.

At $11^h\ 30^m$ A.M. 40 grs. of urea in 5 ounces of distilled water.

At $1^h\ 30^m$ P.M. 7 ounces of acid urine gave evidence of nitric acid by the starch test.

At $5^h\ 30^m$ P.M. nitric acid was present.

Up to $9^h\ 30^m$ A.M. In the total quantity passed nitric acid, in small quantity, was found by the starch test.

In order to determine whether the same effect would be produced out of the body by combustion of the urea, some urea was dissolved in alcohol, the specific gravity of the solution =·851; it was burnt in a spirit-lamp; the products of combustion were collected for one hour. The carbonate of potash solution was examined for nitric acid, and without any concentration it was found by all the tests.

Thus, then, whether in the body or out of the body, urea, by oxidation, gives rise to nitric acid.

In St. George's Hospital the urine of two patients with dropsy and albuminous urine, in whose blood urea might be considered to be probably present, was examined for nitric acid. In each case a pint of the urine was boiled, filtered and distilled, but no trace of nitric acid was found. In one case the experiment was repeated with two pints of urine, but still only a negative result was obtained.

These experiments with urea showed that when small quantities were taken no nitric acid could be detected; this led me to suppose that a large dose of the alkaloids would be necessary to produce any decided effect on the urine, and on this account no alkaloid was taken.

Caffein, however, was dissolved in alcohol, and when burnt for one hour in a spirit-lamp, it gave rise to nitric acid.

As it appeared from these experiments that nitric acid was produced more readily and frequently than has been supposed to be the case, I was led to try whether combustions in the atmosphere, without ammonia, could not give nitric acid.

I first tried the products of the combustion of alcohol. The spirit-lamp was used as before, and the products of combustion were passed through a solution of pure carbonate of potash. The alcohol had not the slightest alkaline reaction, but after an hour's combustion nitric acid was proved to exist in the carbonate of potash, by the starch test, and by the indigo test also.

As it was possible that a small quantity of ammonia might have been present in the alcohol, I determined to collect the product of hydrogen burnt in the air. The gas was generated by pure sulphuric acid and distilled water, and it was burnt for one hour; nitric acid was found to be present in the carbonate of potash in small quantity*.

The combustion of coal in a small furnace was then made, so that the products were passed through dilute carbonate of potash ; after an hour no trace of nitric acid could be detected.

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* After this paper was written, I found that SAUSSURE had described a similar experiment in the Annales de Chemie for 1809, vol. lxxi. p. 285. Nitric acid and ammonia were detected by him after the combustion of hydrogen gas in atmospheric air.

The experiment was repeated with a brisker fire, and a trace of nitric acid was found.

By the combustion of a wax candle, a slight trace of nitric acid was detected after it had burnt one hour.

The product of the combustion of ordinary coal-gas gave plenty of nitric acid. To purify it from ammonia, it was passed through dilute sulphuric acid; nitric acid in much smaller quantity than before was then detected.

This experiment was repeated, passing the coal-gas through a tube 3 feet long, full of asbestos and pumice-stone moistened with strong sulphuric acid, and then through a thin layer of strong sulphuric acid. After combustion for an hour, nitric acid was detected by all the tests. When the laboratory air was passed for an hour through the same solution of carbonate of potash, no trace of nitric acid could be detected. When the atmospheric air, as well as the coal-gas, were first passed through tubes containing sulphuric acid, and afterwards burnt for one hour, nitric acid was detected among the products of combustion, by the starch and by the indigo test.

If instead of depriving the gas of ammonia it was made to pass over the vapour of ammonia and then burnt, nitric acid could be detected by the starch test with the greatest certainty after two minutes' combustion; but with the same flame, after six hours' combustion, I was unable to obtain any very considerable quantity of nitrate of potash.

These experiments on the production of nitric acid in all cases of combustion in the air, render it very probable that small quantities of nitric acid exist always in the atmosphere, and that nitric acid will be constantly detected in rain and snow, not only after a thunder-storm, but at all other times also. At least, by adding pure carbonate of potash to rain-water, and evaporating it to a very small bulk, I have succeeded in detecting nitric acid in the water which fell in London, on a continuously rainy day in December. Fourteen pints, when evaporated to two ounces, furnished positive proof of the presence of nitric acid by the indigo, starch and iron tests.

On another day ten pints, evaporated to a very small bulk, gave evidence of nitric acid.

Should nitric acid be found to be present in the air at all times and in all places, its importance to the growth of plants will not be less than that of the ammonia which has been detected there.

Thus, whether in the body or out of the body, the oxidation of ammonia gives rise to a combination of oxygen with nitrogen. Nitrous and nitric acids are produced. It is very difficult to determine the quantity of these acids formed in the body, but the experiments mentioned above prove that some portion of the nitrogen is oxidized in the passage of ammonia through the system.

The importance of this oxidizing action in effecting a change in the injurious substances which happen to be present in the blood, cannot be overlooked, when experiment proves that urea *in transitu* is partly converted into nitric acid. Whether nitric acid is thus made to appear in the urine in any diseases, is a question of great interest.

The conclusions I come to from my experiments are,—

1st. That the action of oxygen takes place in the body, not only on hydrogen, carbon, sulphur and phosphorus, but also on nitrogen.

2ndly. That in all cases of combustion, out of the body and in the body, if ammonia is present, it is converted partly into nitric acid.

3rdly. That the nitrogen of the air is not indifferent in ordinary cases of combustion, but that it gives rise to minute quantities of nitric acid.

The general result is, that the production of nitric acid from ammonia in the body adds another to the many instances of the action of oxygen in Man.

In the formation of water and carbonic acid, oxygenation has long been recognized as the great cause of the animal heat.

In the Philosophical Transactions for 1846 and 1850, I have endeavoured to show that the excretion of phosphoric and sulphuric acids in excess may be the means of ascertaining in what tissue the most energetic action of oxygen is taking place.

In the present paper, it appears that the detection of nitric acid in the urine may lead to the conclusion, that the blood is being freed from ammonia, or from substances closely related to it, as urea, or possibly caffein and other alkaloids.

The same action then takes place in the fluids of the body as occurs in wells and streams when tainted with sulphuretted hydrogen and ammoniacal animal matter. In the body, as well as out of it, from these substances, sulphuric and nitric acids are produced by the purifying action of the oxygen of the atmosphere.

APPENDIX.

On Nitric Acid in Rain-water.

During January, on different wet days, rain-water was collected in London and decreasing quantities were evaporated with perfectly pure carbonate of potash; and I found that nitric acid was always present and could be detected even in a pint of rain-water by the starch test.

Moreover, in rain-water collected about the same time at Kingston in Surrey; at Melbury in Dorsetshire, many miles from any town; and near Clonakilty in the county of Cork, when a south-west wind was blowing, I found distinct evidence of nitric acid.

XVI. *On the Relation of the Direction of the Wind to the Age of the Moon, as inferred from Observations made at the Royal Observatory, Greenwich, from* 1840 *November to* 1847 *December. By* G. B. Airy, *Esq., Astronomer Royal.*

Received December 27, 1850,—Read March 6, 1851.

In the year 1849, in a voyage to Shetland, I heard allusions to the belief entertained generally by Norwegian seamen, that a northerly wind may always be expected about the time of new moon. The expression of this belief was so positive, and the implication of the interests of the persons entertaining it was so distinct, that it appeared to me extremely probable that there was some physical foundation for it. At the first convenient opportunity, therefore, I took measures for discussing, with reference to this question, the directions of the wind at the Royal Observatory, during a period of rather more than seven years, as ascertained from the records of Osler's Self-registering Anemometer. I extended the research so far as to enable every reader to judge whether there is any probable relation between any Direction of Wind and any Age of the Moon.

The collection and summation of the numbers was effected under the immediate superintendence of Mr. Glaisher. Great pains were taken to establish such checks on the operation that error is almost impossible.

The general result is contained in the Table subjoined to this paper. And, while it shows that there is great uncertainty in the verification of an empirical law, even from nearly ninety lunations, it seems very distinctly to negative the asserted law which gave rise to the inquiry.

In explanation of the Table, it is only necessary to remark that the civil day on which the new moon occurred is taken as the day of new moon (at whatever hour the conjunction occurred), and that the other days are counted in succession from it. The moon's synodic period being nearly $29\frac{1}{2}$ days, the month sometimes consists of twenty-nine days, sometimes of thirty, in almost equal proportions in the long run; and thus the numbers in the last horizontal row of figures must, to make them comparable with the others, be very nearly doubled. Although the sums of numbers in the other horizontal lines are not absolutely equal, they are so nearly equal that no remarkable error will be produced by assuming them as equal.

Table exhibiting the number of hours during which the wind blew in each of sixteen equal divisions of the azimuthal circle, and also the number of hours of sensible calm, in the period extending (with very small interruptions) from 1840 November to 1847 December; from the records of **Osler**'s Self-registering Anemometer at the Royal Observatory, Greenwich: arranged in reference to the days of the Moon's Age.

Days of the Moon's Age.	Number of hours of wind in each direction.																Number of hours of calm.	Total number of hours for each day.
	N.	N.N.E.	N.E.	E.N.E.	E.	E.S.E.	S.E.	S.S.E.	S.	S.S.W.	S.W.	W.S.W.	W.	W.N.W.	N.W.	N.N.W.		
1	146	52	84	42	80	6	...	4	194	260	234	282	128	32	40	38	386	2008
2	140	58	86	66	54	4	6	26	200	242	264	174	78	34	74	90	454	2050
3	164	80	52	52	36	32	12	32	166	242	254	180	84	32	36	84	502	2040
4	112	88	48	18	56	10	18	44	198	244	238	220	100	22	14	74	560	2064
5	126	58	62	34	104	22	10	26	126	210	254	250	78	44	44	52	508	2008
6	132	46	110	76	66	20	6	30	132	192	268	214	98	46	46	86	414	1982
7	108	66	84	72	102	12	26	20	120	206	288	148	176	28	44	54	488	2042
8	116	72	96	58	66	18	4	14	172	174	208	278	124	46	56	56	484	2042
9	150	78	64	48	68	30	10	28	130	160	246	244	96	56	48	80	540	2076
10	190	62	106	32	98	18	18	36	170	184	188	162	138	44	36	74	530	2086
11	184	76	88	52	66	16	10	22	144	210	204	212	120	20	54	76	534	2088
12	100	92	98	66	50	12	6	22	168	116	204	264	146	44	26	48	576	2038
13	194	72	68	58	74	18	12	32	172	110	166	170	104	44	46	76	608	2024
14	190	72	60	80	78	24	20	34	156	144	206	164	82	24	66	86	568	2054
15	278	86	68	60	86	30	34	30	140	190	206	148	104	30	32	64	478	2064
16	150	84	50	104	86	30	52	26	84	158	252	194	100	28	62	80	524	2064
17	208	70	64	46	78	16	20	16	136	166	244	188	96	14	52	60	590	2064
18	212	82	60	70	98	12	14	42	128	194	188	184	100	20	40	50	558	2052
19	228	68	114	80	104	16	26	44	64	86	166	202	126	36	52	88	510	2010
20	174	80	116	76	138	50	20	24	92	114	176	190	122	38	26	40	544	2020
21	168	56	72	98	168	36	16	40	88	140	216	222	122	38	52	44	496	2072
22	206	68	102	76	118	36	26	32	74	150	170	176	90	42	50	80	562	2058
23	224	70	110	56	62	30	24	48	180	126	196	176	86	32	32	74	506	2032
24	236	72	80	38	42	34	20	24	140	156	242	246	100	28	26	176	378	2038
25	206	64	58	76	52	30	8	22	124	202	238	196	136	28	40	90	476	2046
26	126	46	72	100	70	18	16	14	114	178	230	164	164	30	56	78	532	2008
27	98	58	100	64	26	8	10	24	192	210	286	230	88	28	22	26	518	1988
28	88	68	48	68	74	28	32	50	154	190	322	286	92	22	30	50	402	2004
29	82	64	74	60	106	18	4	10	180	198	220	226	170	44	32	50	454	1992
30	80	26	32	30	20	...	2	16	96	124	110	154	48	18	12	26	262	1056
Sum for each direction	4816	2034	2326	1956	2226	634	482	832	4234	5276	6684	6144	3296	992	1246	2050	14942	60170

Royal Observatory, Greenwich,
December 24, 1850.

XVII. *On the Action of Nitric Acid on various Vegetables, with a more particular Examination of* Spartium scoparium, *Linn., or Common Broom.*

By John Stenhouse, *Esq., Ph.D., F.R.S.*

Received November 18,—Read December 12, 1850.

THE last paper which I had the honour of presenting to the Royal Society contained an account of the effects produced by the action of sulphuric and hydrochloric acids on the *matière incrustante* of several plants belonging to the different great classes of vegetables. In the present paper I intend to describe the effects of nitric acid upon a variety of vegetable groups; these researches having been undertaken in the hope that, by means of this powerful reagent, some light might perhaps be thrown on peculiarities in their respective constitutions.

Populus balsamifera.

The first plant experimented on with this view was the *Populus balsamifera*, as representing the numerous family of the Poplars. A quantity of the branches of this, in Great Britain, very common tree, was therefore cut into small pieces and was boiled with water till it was completely exhausted. The dark-coloured bitter-tasted liquid which it yielded was evaporated to the state of an extract. This extract was then digested with dilute nitric acid for about four and twenty hours. A great deal of nitrous fumes were given off, together with a small quantity of an agreeably smelling aromatic oil. The strongly acid solution was evaporated to dryness on the water-bath, so as to drive off as much of the adhering nitric acid as possible. The dried residue was next dissolved in a considerable quantity of hot water, and after being allowed to cool, was carefully filtered through a cloth. The clear liquid was then concentrated by cautious evaporation, and exactly saturated in the cold with carbonate of potash, great care being taken not to add an excess of the alkali. A yellow sediment soon began to appear, and its amount was greatly increased in the course of a few hours. It consisted of nitropicrate of potash and of the potash salt of a new acid, to which I have given the name of nitropopulic acid. The mother-liquor contained a great deal of oxalate and nitrate of potash. The mixed precipitates were then collected on a filter and dried by pressure, so as to remove as much of the adhering mother-liquor as possible. They were then washed with a little cold water and were treated with a cold solution of dilute carbonate of potash, which readily dissolved out the nitropopulate of potash, while it left the nitropicrate of potash unacted on. The two salts were then separated by filtration, the nitropicrate of potash remaining on the filter, while the nitropopulate of potash was dissolved in the alkaline liquid. The mother-liquor was again slightly supersaturated with muriatic acid, when the nitropopulate of potash precipitated as a compact crystalline powder, which was collected on a filter and washed with a little cold water. It was dissolved a second time in a dilute solution of carbonate of potash, and again precipitated by muriatic acid. The object of this second treatment with an alkaline carbonate, was to remove any trace of nitropicrate of potash which might adhere to it. The nitropopulate of potash was still further purified by being digested with animal charcoal, and repeatedly crystallized out of hot water. No potash was added in these latter crystallizations, because an excess of potash, when assisted by heat, has the effect of decomposing nitropopulic acid. When, through these operations, the nitropopulate of potash has been sufficiently purified, it has merely a pale lemon-yellow colour, and may be employed for preparing nitropopulic acid. It is therefore boiled with a very considerable excess of muriatic acid, and on the cooling of the solution, the nitropopulic acid is deposited in silky needles, forming concentric groups of a pale yellow colour. Nitric acid cannot be advantageously employed for this purpose instead of muriatic acid, for, as will subsequently appear, nitropopulic acid is destroyed when it is boiled with strong nitric acid. The nitropopulic acid in this stage of its preparation is not altogether free from a small quantity of a yellowish colouring matter, which adheres to it with great tenacity. Its crystals require, therefore, to be again dissolved in dilute muriatic acid; and they are subsequently still further purified by being repeatedly digested with animal charcoal, and crystallized out of hot aqueous solutions. The crystals of nitropopulic acid, when quite pure, are perfectly colourless, and the solution from which they have crystallized has only a slightly yellowish shade. The pure nitropopulic acid requires to be pretty quickly separated from the mother-liquor by being pressed between folds of blotting-paper and immediately dried *in vacuo*, as when it is exposed to the air, even for a short time, it is very apt to become yellow. When it is deposited by slow cooling out of dilute aqueous solutions, it forms hard prismatic crystals arranged in concentric groups; but when a hot concentrated solution of the acid is rapidly cooled, it becomes filled with a mass of long slender silky needles. Muriatic acid has the effect of preventing the oxidation of nitropopulic acid, which may be readily obtained from a dilute solution of that acid in colourless crystals.

Nitropopulic acid is very soluble in water, and still more so in weak and strong spirits of wine. An addition of sulphuric or muriatic acid to its aqueous solution has the effect of considerably diminishing its solubility, and the colour of the solution becomes fainter in proportion as the amount of the mineral acid is increased. But when the acid solution is diluted with water, the yellow colour again reappears. When an excess of nitropopulic acid is boiled with dilute muriatic acid part of it dissolves, while the portion which remains undissolved melts and forms a yellowish oil, which solidifies and crystallizes when the liquid cools. Nitropopulic acid may likewise be gently heated in sulphuric acid without being decomposed, and it crystallizes again when the solution cools. When nitropopulic acid, however, is digested with pretty concentrated nitric acid, it is decomposed, being converted into nitropicric acid. If nitropopulic acid is boiled with a mixture of hydrochloric acid and chlorate of potash, it is also decomposed, being changed into chloranil. When nitropopulic acid is treated with a cold solution of hypochlorite of lime, no effect is produced; and even when the mixture is treated to nearly the boiling-point, no chloropicrine is evolved; but when it has been boiled for a few minutes, a sudden effervescence takes place, and the nitropopulic acid gives off abundance of chloropicrine. This reaction is highly characteristic of nitropopulic, indigotic and chrysammic acids, and furnishes an easy test by which any of these acids may be immediately distinguished from either nitropicric or oxypicric acids, both of which evolve chloropicrine, either in the cold, or when very gently heated with hypochlorite of lime.

I must here rectify a slight error which I committed, in a short notice upon indigotic acid, which I published about two years ago. I then stated that indigotic acid might be heated with a solution of hypochlorite of lime without the production of chloropicrine. This is so far quite true; but if, as has just been stated, the mixture is boiled for some minutes, effervescence ensues and chloropicrine is abundantly evolved. Nitropopulic acid may also be easily distinguished from the above-mentioned acids by the peculiar character of its potash salt. For though, as already stated, nitropopulate of potash is very slightly soluble in pure water, it dissolves very readily in an alkaline solution, and is precipitated again when the solution is neutralized with an acid. The potash salts of nitropicric, chrysammic and oxypicric acids, on the contrary, are less soluble in alkaline lyes than they are in pure water. And indigotate of potash, though it resembles the nitropopulate of that base, in being very soluble in alkaline solutions, differs from it in being much more soluble in cold water, and in being much more easily decomposed by any of the stronger acids. Thus, when a concentrated solution of indigotate of potash is treated in the cold with a slight excess of muriatic acid, the salt is decomposed and a considerable portion of the indigotic acid is precipitated. Nitropopulate of potash, on the contrary, can only be decomposed when it is boiled with a great excess of muriatic acid. The small amount of solubility in cold water which the neutral potash, soda and ammonia salts of nitropopulic acid exhibit, is quite characteristic, and distinguishes them from the corresponding salts of indigotic acid. The taste of nitropopulic acid is very peculiar, being at first very strongly acid like oxalic acid, then astringent, and finally exceedingly bitter. Nitropopulic acid stains the skin permanently yellow. When gently heated in a retort, it sublimes and crystallizes on cooling. When strongly heated in the open air, it burns with a bright yellow flame, and when any of its salts are heated on platinum foil, they explode with considerable violence. Nitropopulic acid strikes a deep red colour with a solution of perchloride of iron. With the protosulphate of iron it merely yields a deep yellow.

The chief points which require to be attended to in preparing nitropopulic acid, may be shortly stated as follows:—The mixture of dilute nitric acid and the extract of the *Populus balsamifera*, must never be so highly heated as to boil; for if the heat is allowed to rise very high and the acid is concentrated, almost the whole of the nitropopulic acid will be decomposed, being changed into nitropicric acid. In this respect nitropopulic acid resembles indigotic acid, which, by digestion with strong nitric acid, is also converted into nitropicric acid. When the mixture of the crude acids is dissolved in water, it must be filtered only when perfectly cold, so as to separate the resinous matter of the extract and retain it upon the filter. This resinous matter, which has usually a deep green colour when it is treated a second time with nitric acid, yields a second quantity of the mixed nitrogenated acids. It is also necessary to precipitate the mixture of the nitropicric and nitropopulic acids both together by exactly saturating them with potash, and to withdraw them from the mother-liquor before we attempt to separate the mixture of the two salts from each other; for if much resinous matter and any considerable amount of inorganic salts are contained in the solution, neither the nitropicrate nor the nitropopulate of potash readily crystallizes out of it. The mother-liquor always contains a large quantity of quadroxalate of potash and free oxalic acid, the removal of which latter substance cannot be effected by means of lime, as the basic lime-salt of nitropopulic acid is scarcely more soluble in water than the neutral oxalate of lime. It is likewise very necessary to exclude the air from nitropopulic acid as much as possible during its purification; and the dried acid should be preserved in well-stoppered bottles, as it rapidly becomes yellow on exposure to the air.

Nitropopulic acid, when dried first in the air and then *in vacuo,* loses 7·21 per cent. water. Thus 0·957 grm. lost *in vacuo* 0·069=7·21 per cent.

The nitropopulic acid dried *in vacuo,* when burned with oxide of copper and copper turnings, gave the following results:—

I. 0·323 grm. of acid gave 0·4355 CO_2 and 0·05 water.

II. 0·339 grm. of acid gave 0·455 carbonic acid and 0·058 water.

The nitrogen was determined qualitatively by Liebig's method.

Tubes.	Vol. mixed gases.	Vol. after absorption, or N.	Vol. of carbonic acid.
1	33	4	29
2	25	3	22
3	32	4	28
4	39	5	34
5	24	3	21
6	27	3½	23½
7	33	4	29
8	35	4½	30½
9	29	3½	25½
10	33	4	29
11	32	4	28
12	43	5½	37½
13	37	4½	32½
14	28	3½	24½
15	36	4½	31½
16	33	4	29
17	27	3½	23½
18	32	4	28
	578	72	506

It is plain from these determinations that the nitrogen in the acid is to the carbon almost exactly in the proportions of 2 to 14 or of 1 to 7, and when calculated accordingly, they have given the subjoined result, 12·23 per cent. nitrogen.

				I.	II.
C	14	1050·00	36·84	36·77	36·64
H	4	50·00	1·75	1·71	1·79
N	2	350·50	12·30	12·23	12·23
O	14	1400·00	49·11	49·29	49·34
		2850·50	100·00	100·00	100·00

1 equivalent of nitropopulic acid dried first in the air and then

		Calculated.		Found.
in vacuo	=	2850·50	=92·69	92·79
2 equivs. water		225·00	7·31	7·21
		3075·50	100·00	100·00

The formula of the acid dried *in vacuo*, as confirmed by the analysis of the potash and silver salts subsequently given, is therefore $C_{14}\ H_3\ N_2\ O_{13}+HO$, and the formula of the acid dried in the air $C_{14}\ H_3\ N_2\ O_{13}+HO+2Aq$.

Nitropopulate of Potash.

One portion of this salt was prepared by digesting crude nitropopulate of potash with animal charcoal and repeatedly crystallizing it out of water. The pure salt had a lemon-yellow colour and consisted of small prisms. It is very slightly soluble in cold water, but exceedingly soluble in alkaline solutions. A second portion of the purified salt was crystallized out of a solution which had been rendered slightly alkaline by the addition of a few drops of potash. Both portions of the salt were dried first *in vacuo*, and then in the water-bath at 212° FAHR., when they lost no water.

Their analysis was conducted as follows:—A weighed portion of each salt was gently heated in a covered platinum crucible with a few drops of sulphuric acid, and after the mixture of acids had been cautiously volatilized, the heat was considerably increased. A little more sulphuric acid was then added, and the excess of the acid removed by heating the sulphate with a little carbonate of ammonia.

I. 0·300 grm. of salt gave 0·0987 $KO\ SO_3$=0·0532 potash=17·73 per cent.

II. 0·299 grm. of salt gave 0·097 $KO\ SO_3$=0·047 KO=17·42 per cent.

0·2723 grm. of salt gave 0·317 carbonic acid and 0·029 water.

Calculated numbers.				I.	II.
C	14	1050·00	31·57	31·74	
H	3	37·50	1·12	1·17	
N	2	350·50			
O	13	1300·00			
KO		588·00	17·70	17·73	17·42
		3326·00			

Nitropopulate of Silver.

The silver salt was prepared by dissolving oxide of silver in a hot solution of pure nitropopulic acid. On the cooling of the liquid the salt was deposited in small hard granular crystals, which were dried at 212°, and subjected to analysis.

0·448 grm. of salt gave 0·190 chloride of silver=0·1536 oxide of silver.

I. 0·6205 grm. of salt gave 0·562 carbonic acid and 0·055 water.

II. 0·379 grm. of salt gave 0·347 carbonic acid and 0·031 water.

		Calculated numbers.		I.	II.
C	14	1050·00	25·07	24·70	24·97
H	3	37·50	00·89	00·98	00·90
N	2	350·50			
O	13	1300·00			
AgO		1449·01	34·60	34·28	
		4187·01			

Nitropopulate of Soda.

This salt was prepared by exactly saturating a hot solution of nitropopulic acid with carbonate of soda. On the cooling of the liquid the soda salt was deposited in small acicular crystals, which, like the potash salt, were very slightly soluble in cold water.

0·1700 grm. of salt dried *in vacuo* gave 0·048 sulphate of soda=0·0209. NaO=12·29 per cent.

		Calculated.		Found.
C	14	1050·00		
H	3	37·50		
N	2	350·50		
O	13	1300·00		
NaO		387·00	12·39	12·29
		3125		

The nitropopulate of ammonia is prepared in exactly the same way as the potash and soda salts, and its solubility and reactions are very similar to theirs.

The neutral baryta salt is readily formed by adding a hot solution of baryta to a hot solution of nitropopulic acid. The addition of the baryta is cautiously continued so long as the precipitate which falls is redissolved on shaking the flask. The filtered liquid deposits, on cooling, small granular crystals, which, after being dried *in vacuo* and afterwards in the water-bath, appear to have the following composition:—

0·231 grm. salt, when treated with sulphuric acid, gave 0·091 $BaO\ SO_3$=0·0597 BaO=25·84 per cent.

		Calculated numbers.		Found.
C	14	1050·		
H	3	37·50		
N	2	350·50		
O	13	1300·00		
BaO		954·85	25·85	25·84
		3692·00		

Basic Nitropopulate of Baryta.

This salt is obtained by adding a hot solution of caustic baryta to a hot solution of nitropopulic acid, so long as a precipitate is formed. This precipitate, which consists of very minute crystals, must be immediately collected on a filter and thoroughly washed with boiling distilled water, in which it is nearly insoluble. It was also first dried *in vacuo*. When it was afterwards heated in the water-bath to 212° Fahr., it did not lose any weight.

0·241 grm. salt gave 0·151 $BaO\,SO_3$=0·0991 BaO=41·12 per cent.

		Calculated numbers.		Found.
C	14	1050·00		
H	3	37·50		
N	2	350·50		
O	13	1300·00		
BaO	2	1909·00	41·08	41·12
		4647·		

The formula of this salt therefore is $C_{14}\,H_3\,N_2\,O_{13}\,(BaO)_2$.

Nitropopulate of Lead.

Both the neutral and basic lead salts of nitropopulic acid may be readily obtained by treating a hot solution of the potash salt with neutral or basic acetate of lead. Both of these lead salts are uncrystallizable and insoluble in water.

Populus nigra.

As I was anxious to ascertain if nitropopulic acid could likewise be obtained from the various other species of Poplar as well as from the *Populus balsamifera*, a quantity of the small branches of the *Populus nigra* was cut into pieces, boiled with water, and the solution concentrated to the state of an extract, exactly in the way already described. This extract was also digested with dilute nitric acid. The products were found to consist chiefly of an acid, having all the external characters of nitropopulic acid, together with a considerable amount of nitropicric acid. In order to ascertain, however, that the supposed nitropopulic acid was really what it appeared to be, a quantity of it was purified in the way already detailed, and subjected to analysis.

0·2325 grm. of the acid, dried *in vacuo*, gave 0·314 CO_2 and 0·040 HO.

	Calculated numbers.	Found numbers.
C	36·84	36·81
H	1·75	1·90

Two quantities of the potash salt, prepared at different times, were also subjected to analysis.

I. Prep. 0·2355 grm. salt gave 0·0378 $KO\,SO_3$=0·0421 KO=17·45 per cent.

II. Prep. 0·214 grm. salt gave 0·07 $KO\,SO_3$=0·0378 KO=17·65 per cent.

The calculated quantity of potash in the nitropopulate of that base is 17·70 per cent. From these determinations, therefore, there can be no doubt that the *Populus nigra* also yields nitropopulic acid. I think there is good reason for expecting, therefore, that the other species of Poplars will also yield nitropopulic acid, which I believe will be found characteristic of the Poplar tribe.

It has long been known, through the researches of BRACONNOT and other chemists, that the family of Poplars contains two crystallizable, very analogous principles, viz. salicine and populine. Now salicine, as was first observed by PIRIA, when it is distilled with a mixture of bichromate of potash and sulphuric acid, yields salicylous acid. On subjecting, therefore, separate quantities of the extracts of *Populus balsamifera* and *P. nigra* to distillation with bichromate of potash and sulphuric acid, I succeeded in procuring a considerable amount of salicylous acid from both of them. There is every reason to believe, therefore, that both of these Poplars contain salicine, which is probably the source of much of the nitropicric acid which they yield when digested with nitric acid. The nitropopulic acid, which appears characteristic of the Poplar tribe, I strongly suspect will be found to result from the action of nitric acid upon the populine they contain; though, for the present, I only throw out this idea as a probable conjecture.

In order to be quite certain that the other nitrogenous organic acid obtained from both these Poplars, and accompanying the nitropopulic acid, was really the nitropicric acid, as its external characters seemed to indicate, a quantity of its purified potash salt was subjected to analysis.

0·555 grm. salt gave 0·182 sulphate of potash=0·0984 potash.

0·4075 grm. salt gave 0·401 CO_2 and 0·028 water.

	Calculated numbers.		Found numbers.
12 C	900·00	26·94	26·83
2 H	25·00	0·75	0·76
3 N	525·75	15·74	
13 O	1300·00	38·94	
KO	588·94	17·63	17·73
	3339·69	100·00	

It is clear from these results that the acid in question is really the nitropicric, just as I had previously supposed.

In conclusion, I subjoin a tabular view of the formulæ of nitropopulic acid and its salts:—

Nitropopulic, dried *in vacuo* . . .	$HO, C_{14} H_3 N_2 O_{13}$
Nitropopulic, dried in the air . .	$HO, C_{14} H_3 N_2 O_{13}+2 Aq$
Potash salt	$KO, C_{14} H_3 N_2 O_{13}$
Soda salt	$NaO, C_{14} H_3 N_2 O_{13}$
Neutral baryta salt	$BaO, C_{14} H_3 N_2 O_{13}$
Basic baryta salt	$2BaO, C_{14} H_3 N_2 O_{13}$
Silver salt	$AgO, C_{14} H_3 N_2 O_{13}$

The following are the formulæ of a few of the other nitrogenated acids which most closely resemble nitropopulic acid:—

Indigotic acid	$HO, C_{14} H_4 N O_9$
Nitropopulic acid	$HO, C_{14} H_3 N_2 O_{13}$
Nitrophenesic acid	$HO, C_{12} H_3 N_2 O_{13}$
Nitropicric acid.	$HO, C_{12} H_2 N_3 O_{13}$
Oxypicric acid	$HO, C_{12} H_2 N_3 O_{15}$

It is plain, therefore, that nitropopulic acid only differs from nitrophenesic acid by two equivalents of carbon.

Salix Russelliana, or Bedford Willow.

An extract was prepared from the wood and branches of the *Salix Russelliana*, exactly in the way already described in the two preceding instances. When digested with dilute nitric acid, it yielded a great deal of oxalic and nitropicric, but no nitropopulic acid. The following pretty numerous list of trees and shrubs, when treated with nitric acid, also yielded oxalic and nitropicric acids:—

1. *Cytisus laburnum*, or the Laburnum-tree.
2. *Swietenia mahogani*, or Mahogany Wood.
3. *Pyrus malus*, or the Apple-tree.
4. *Cratægus oxyacantha*, or the Hawthorn.
5. *Ribes nigrum*, or the Black Currant-bush.
6. *Betula alnus*, or the Alder.
7. *Ulex europæus*, or the Furze.
8. *Calluna vulgaris*, or Common Heather.
9. The root of the *Curcuma longa*, or Turmeric.
10. Extract of seeds of the *Bixa orellana*, or Annotto.
11. *Sambucus nigra*, or Common Elder.
12. *Cytisus scoparius*, the *Spartium scoparium* of Linn., or Common Broom.

The extracts of *Quercus robur*, or Common Oak, and of *Betula alba*, the Beech-tree, when digested with nitric acid, only yielded oxalic acid, but no nitropicric or any analogous nitrogenated acid. It is somewhat remarkable, therefore, that of the extracts of seventeen vegetable substances no fewer than fifteen should, when treated with nitric acid, yield nitropicric acid; while two of their number, in addition to nitropicric, should also yield nitropopulic acid, and only two out of the seventeen should produce oxalic acid, unaccompanied by a nitrogenous organic acid.

The results of these experiments seem to indicate therefore that a far greater number of plants are capable of yielding nitropicric acid than has generally been supposed, those which fail to do so apparently constituting a very small minority. I fully expected to have met with a greater variety of nitrogenated acids, and am rather surprised that I did not find either the indigotic or oxypicric acids.

As the extract of broom, *Spartium scoparium*, besides yielding nitropicric acid, exhibited some interesting peculiarities, I was induced to subject it to a more minute examination, the results of which I now briefly subjoin.

Spartium scoparium, Linn.

The first portion of broom operated on was grown on low-lying sandy ground in an open, sunny situation, about two miles to the east of Glasgow. I mention this circumstance from a reason which will subsequently appear. The broom plants, though full-grown, were only from two to two and a half feet in height, and had an exceedingly bitter taste. They were cut into small pieces and then boiled for six or eight hours with a considerable quantity of water, till they were thoroughly exhausted. The decoction was evaporated down to about one-tenth of its bulk, and set aside in a cool place for four-and-twenty-hours. It was then found to have gelatinized into a greenish-brown, coherent mass, which was thrown upon a cloth filter and washed with a little cold water. This very impure jelly consisted chiefly of a crystalline yellow colouring matter (scoparine), which was contaminated with a considerable amount of chlorophyl and oxide of iron, derived from the iron vessel in which the decoction of the broom had been made. It also contained a small quantity of a volatile organic base (sparteine), which gave the jelly its extremely bitter taste. In order to obtain the scoparine in a pure crystalline state, the first step taken was to dissolve the crude jelly by boiling it with a considerable quantity of water, acidulated with a little hydrochloric acid. The hot aqueous solution was then poured through a funnel, the neck of which was imperfectly stopped with a little cotton wool. The clear liquid which passed through coagulated on cooling again into a greenish-yellow jelly, which was collected on a filtering cloth and again washed with a little cold water. The jelly was then gently compressed to remove the greater portion of the adhering mother-liquor, and was evaporated to dryness on the water-bath. The impure scoparine, when thoroughly dried, was reduced to powder and again dissolved in boiling water, while the greater portion of the chlorophyl having been rendered insoluble remained behind. Instead of evaporating the crude gelatinous scoparine to dryness, in the way just described, the greater portion of the chlorophyl adhering to it may likewise be separated either by long-continued boiling or by filtering its solutions after they have cooled to a certain degree, the impure portion of the scoparine being that which is first deposited. The gelatinous scoparine obtained by either of these methods, when dried at a moderate temperature, either in the open air or *in vacuo*, forms a pale yellow, or sometimes greenish-yellow, brittle mass, which is perfectly amorphous. It is very slightly soluble in cold water, a little more so in cold spirits of wine, but pretty soluble in boiling water and in hot spirits. The colour of its aqueous solution is pale yellow with a greenish shade,that of its alcoholic is pale yellow. It dissolves readily in the caustic and carbonated alkalies, forming deep greenish-yellow solutions. When scoparine has been dissolved in a cold solution of ammonia or carbonate of soda, and the alkali is slightly supersaturated with either hydrochloric or acetic acids, the scoparine is thrown down as a white precipitate, which appears however to be a little more compact and denser than before its solution in the alkali. When this precipitate, after being washed to remove any adhering sal-ammoniac, is again dissolved in boiling water, it forms a pale yellow solution, which, when it is allowed to cool very slowly, deposits a quantity of pale yellow prisms arranged in stars, which attach themselves to the bottom and sides of the containing vessel, while some gelatinous scoparine remains floating in the centre of the liquid.

As scoparine appeared to crystallize out of its aqueous solutions with considerable difficulty, a quantity of it, while still but imperfectly purified, was evaporated to dryness on the water-bath and then treated with boiling spirits of wine. A small portion of it remained undissolved, and the yellowish solution, which was formed after it had remained for a day in a covered glass vessel, did not crystallize; but when a portion of the alcohol was slowly evaporated, the scoparine precipitated in the gelatinous state. The solution was therefore again heated, when the gelatinous matter dissolved; and on leaving the solution to spontaneous evaporation, in the course of two or three days the bottom and sides of the glass became covered with short prisms of scoparine, arranged in little stars, precisely similar to those obtained by slow cooling from the aqueous solution. These crystals were then dried by pressure between folds of bibulous paper and were again dissolved in hot spirits of wine, and after twelve hours they crystallized in short prisms of a pale yellow colour and possessing considerable lustre. If these crystals are boiled with a quantity of strong or absolute alcohol, insufficient for their entire solution, a portion dissolves, while that which remains appears to undergo a kind of molecular change, and becomes more difficultly soluble, both in hot alcohol and in water. It may be easily restored to its original state again (from this apparently allotropic condition) by dissolving it in ammonia and neutralizing with acetic acid, when the scoparine precipitates as a jelly and becomes as soluble as before. If it is then treated therefore with boiling water it readily dissolves, and on allowing the solution to cool very slowly, the scoparine crystallizes out in small stars, possessing all its original properties.

Scoparine, when prepared in any of the ways above described, has, as we shall presently see, invariably the same composition. It is tasteless and inodorous, and does not affect either litmus or turmeric paper. It dissolves very readily in caustic and carbonated alkalies, and it is also soluble, to some extent, in concentrated acids, the colour of its solutions being greenish yellow. When the alkaline or acid solutions of scoparine are boiled it is slowly decomposed, being changed into a greenish-brown resinous matter. Scoparine dissolves pretty readily in lime and baryta water, but not nearly to the same extent as in ammonia and the fixed alkalies. When its ammoniacal solution is left to spontaneous evaporation in the open air, almost the whole of the ammonia volatilizes and the residue forms a greenish gelatinous mass. A solution of hypochlorite of lime changes scoparine to a deep green colour, probably by oxidizing it, and when it is digested with nitric acid it is converted into nitropicric acid. Bromine changes the colour of gelatinous scoparine into brownish-yellow, but yields no crystalline product. A solution of scoparine produces no precipitate, either with corrosive sublimate or nitrate of silver. With neutral and basic acetate of lead it yields greenish yellow, flocculent precipitates, which are neither copious nor stable. Scoparine, when dried *in vacuo,* did not lose any weight when afterwards heated to 212° Fahr. When sufficiently heated in a glass tube, it melts into a dark brownish resin, but yields no sublimate. When strongly heated in the open air, it catches fire and burns with a bright yellow flame.

I. Of scoparine, crystallized several times out of ordinary spirit of wine, 0·2740 grm., dried *in vacuo,* gave 0·578 carbonic acid and 0·134 water.

II. 0·286 grm. scoparine, crystallized out of absolute alcohol, gave 0·606 carbonic acid and 0·135 water.

III. 0·2725 grm. gelatinous scoparine, out of absolute alcohol, gave 0·578 carbonic acid and 0·133 water.

IV. 0·210 grm. residue of scoparine, left from the treatment with alcohol, dissolved in ammonia, precipitated with acetic acid and crystallized out of hot water, gave 0·444 carbonic acid and 0·099 water.

V. 0·2775 grm. gelatinous scoparine, purified only with water, gave 0·586 carbonic acid and 0·131 water.

Calculated numbers.			Found numbers.				
			I.	II.	III.	IV.	V.
21 C	1575·0	58·09	57·53	57·76	57·83	57·66	57·60
11 H	137·5	5·06	5·43	5·24	5·41	5·23	5·42
10 O	1000·0	36·88	37·04	37·00	36·76	37·11	36·98
	2712·5	100·00	100·00	100·00	100·00	100·00	100·00

The formula $C_{21}\,H_{11}\,O_{10}$, which has been deduced from these analyses of scoparine, is merely empirical, as I have not as yet been enabled to obtain any definite combination from which its atomic weight might be ascertained. From what has been stated above respecting scoparine, it evidently belongs to the pretty numerous class of colouring matters, which, if they can be said to possess any determinate chemical character, are merely extremely feeble acids. Indeterminate, however, as the chemical characters of scoparine certainly are, and notwithstanding its seeming inertness, it appears to possess important medical virtues; for from a pretty extensive series of experiments, made both on animals and men, I am induced to conclude that scoparine is the diuretic principle of broom. Broom was highly prized and recommended as a diuretic both by Mead and Cullen, who found it highly effective in the reduction of dropsical affections; and in more modern times, Drs. Pearson and Pereira recommend it as more certain than any other diuretic in dropsies. I shall advert to this subject again, however, before the close of the paper.

Sparteine.

The acid mother-liquor from the crude scoparine, after having been concentrated to a very moderate bulk, was introduced along with a considerable excess of soda into a capacious distilling apparatus. As the somewhat viscid liquor was very apt to froth up and come over, only a very moderate heat was applied at first; but as the distillation proceeded the fire was increased, and the boiling was kept up pretty briskly, fresh quantities of water being added so long as the liquid which distilled over had a strongly bitter taste. These liquids were then mixed, and were repeatedly rectified with an excess of common salt. During the concluding rectification, the first portion of the liquid which came over contained a considerable amount of ammonia, and as the distillation proceeded a small quantity of colourless heavy oil (sparteine) began to appear, and soon sunk to the bottom of the receiver. The amount of the oil obtained from any one portion of the distilled liquid was never great, but it continued to come over for a very long time, so that by pouring back into the still the clear liquid which had deposited its oil and redistilling it, new quantities of oil continued to be obtained for a very considerable length of time.

The sparteine procured in the way just described is easily freed from any adhering ammonia by being washed with successive quantities of cold water, in which this oily base is but very slightly soluble. Sparteine is a somewhat viscid colourless oil, which when first distilled is quite transparent, but on remaining for some hours in contact with water, it becomes slightly opalescent. In the course of a week or two a thin white coating forms at the line of junction with the water, and if but a small quantity of water is present, it is absorbed by the base, a hydrate being probably produced. When sparteine is exposed to the air for some days, it gradually acquires a brownish yellow colour. It is considerably heavier than water and has a feeble smell, somewhat resembling that of aniline. It has a distinctly alkaline reaction, neutralizing the strongest acids perfectly. Sparteine and its salts have an extremely bitter taste. When brought in contact with hydrochloric acid sparteine immediately combines with it, though owing to the slight amount of volatility in the base scarcely any white vapours are evolved. Neither its acid or its neutral solution in hydrochloric acid, though evaporated *in vacuo*, could be made to crystallize, and I was not more successful with the nitrate. When sparteine was boiled for a considerable length of time with an excess of fuming nitric acid, it was slowly decomposed. The solution was concentrated to drive off the excess of acid, and on adding a little water a slight flocculent precipitate fell (probably a resin), while a clear yellow solution was obtained. On treating one portion of this solution with hypochlorite of lime, chloropicrine was evolved; and on saturating a second portion of it with potash and distilling, a few drops of an apparently new base were produced. When sparteine is boiled for a considerable time with an excess of strong hydrochloric acid, it seems also to be partially decomposed, as it acquires an odour resembling that of mice. When a few drops of bromine are poured upon a little sparteine much heat is produced, and the sparteine is changed into a brownish resin. Bleaching powder exhibits no peculiar reaction with sparteine; and when this base is distilled with fused potash no aniline is produced.

A quantity of sparteine was dried by contact with fused chloride of calcium, and when poured off from the latter substance was rectified in a small glass retort. The sparteine, owing to its extremely high boiling-point, 550° FAHR., distilled over very slowly and had a yellowish shade. A second quantity of it was rectified in a current of dry carbonic acid gas with a much better result, as it then came over nearly colourless. Its odour was however slightly altered, having become somewhat less agreeable. It will be presently seen from its analysis, and from those of its salts, that the sparteine had undergone no essential alteration. Another quantity of perfectly colourless sparteine which had been rectified along with the vapour of water, and consequently at a much lower temperature, was dried *in vacuo* over sulphuric acid, till it ceased to lose weight. This required about ten days. The oil had also acquired a faintly yellowish shade, but remained quite transparent, and its odour was unaltered.

I. 0·247 grm. sparteine, dried by chloride of calcium, gave 0·6945 carbonic acid and 0·246 water.

II. 0·2545 sparteine, dried *in vacuo*, gave 0·716 carbonic acid and 0·256 water.

Calculated numbers.			I.	II.
15 C	1125·0	76·91	76·68	76·70
13 H	162·5	11·10	11·02	11·17
N	175·2	11·99		
	1462·7	100·00		

Nitropicrate of Sparteine.

As the more common simple salts of sparteine, such as the hydrochlorate, nitrate, &c., were found to be so very soluble and difficultly crystallizable, it seemed desirable to try whether perhaps some organic salt might prove more suitable in this respect. Accordingly nitropicric acid, on account of its sparing solubility, was selected for this purpose. A saturated solution of nitropicric acid, made with cold spirits of wine, was therefore heated to nearly 212° FAHR., and was then added to a hot alcoholic solution of sparteine. At first the nitropicric acid threw down a yellow milky precipitate, which redissolved when the solution was agitated. But when a sufficiency of the nitropicric acid had been employed, a permanent bulky crystalline precipitate was produced, which was collected on a filter and washed with hot water. It was then digested with a considerable quantity of boiling spirits of wine and filtered. The clear solution, on cooling, deposited the nitropicrate of sparteine in long shining needles, from 1 to 2 inches in length. These crystals are very brittle, and so closely resemble nitropicrate of potash in appearance, that they cannot be distinguished from that salt by the eye. Nitropicrate of sparteine is very slightly soluble, either in cold water or alcohol; and it is by no means very soluble even in boiling water or spirits of wine, so that it can be readily crystallized out of either of these liquids. It is also a very stable salt, so that it is not altered by exposure to the air; and even when it is treated with a dilute solution of potash in the cold it is not decomposed. With the assistance of heat, however, nitropicrate of potash is formed while the sparteine is eliminated. When nitropicrate of sparteine is sharply heated it detonates pretty strongly. The portion of the salt subjected to analysis was dried *in vacuo*, and when afterwards heated in the water-bath it lost no additional weight.

I. 0·272 grm. salt gave 0·464 carbonic acid and 0·1165 water.

II. 0·2615 grm. salt gave 0·449 carbonic acid and 0·1145 water.

The nitrogen was determined qualitatively according to Liebig's method; 571 measures of mixed gases yielded 72 measures of nitrogen and 499 of carbonic acid; being nitrogen in the proportion of 8 to 55½ carbonic acid, or nearly as 4 to 27.

Calculated numbers.			Found numbers.	
			I.	II.
27 C	2025·0	46·81	46·51	46·63
16 H	200·0	4·62	4·75	4·86
4 N	700·8	16·20	15·68	15·68
14 O	1400·0	32·37	33·06	32·83
	4325·8	100·00	100·00	100·00

The formula of this salt therefore is $C_{15} H_{13} N, C_{12} H_2 N_3 O_{13} + HO$.

Chloride of Platinum and Sparteine.

When an excess of bichloride of platinum is added to a cold solution of sparteine in hydrochloric acid, a bulky yellow precipitate immediately falls, which is but slightly soluble in either water or alcohol, and when boiled with these liquids it is partially decomposed. It dissolves, however, without decomposition either in hot concentrated hydrochloric acid, or in that acid when diluted with an equal weight of water. The double chloride is deposited from the latter solution in very regularly formed orange-coloured crystals of considerable size and great lustre. These crystals may be generally described as a modification of the rectangular prism, with elongated triangular facets at either extremity, being precisely similar to that form which the ammonio-phosphate of magnesia has when spontaneously deposited from neutral or alkaline urine. The double chloride does not suffer the slightest change by exposure to the air. It was washed with a little cold alcohol, and when dried *in vacuo* was submitted to analysis.

0·224 grm. salt gave 0·065 Pt=29·02 per cent. platinum.
0·709 grm. salt gave 0·203 Pt=28·63 per cent. platinum.
0·369 grm. salt gave 0·106 Pt=28·73 per cent. platinum.
0·466 grm. salt gave 0·134 =28·75 per cent. platinum.
0·4395 grm. salt gave 0·1272 =28·94 per cent. platinum.
0·7204 grm. salt gave 0·2054 =28·51 per cent. platinum.

Mean . . 28·76 Pt.

The preceding determinations of the platinum were made with the salt prepared at several different times.

I. 0·4879 grm. salt gave 0·475 carbonic acid and 0·217 water.

II. 0·3573 grm. salt gave 0·345 carbonic acid and 0·1528 water.

0·8531 grm. salt gave 1·06 Cl Ag=0·2621 Cl=30·72 per cent. chlorine.

	Calculated numbers.		I.	II.
13 C	1125·00	26·38	26·55	26·33
16 H	200·00	4·68	4·99	4·74
N	175·20	4·10		
2 O	200·00	4·73		
Pt	1233·50	28·93	28·76	28·76
3 Cl	1329·60	31·18	30·72	30·72
	4263·30	100·00		

The double chloride of sparteine and platinum, when dried *in vacuo*, has therefore the following formula,

$$C_{15}\,H_{13}\,N,\,Cl\,H+Pt\,Cl_2+2HO.$$

As it was plain from the result of these analyses that the double chloride of platinum and sparteine, when dried *in vacuo*, contained 2 equivs. of water, it was transferred to the water-bath and heated to 212° Fahr.; and as it continued to give off its water very slowly, it was exposed for twelve hours to a temperature of 266° Fahr., when it lost 5·54 per cent. water. The salt then ceased to lose any additional weight, and was not decomposed, though the heat was raised to 300° Fahr.

1·892 grm. salt lost 266° Fahr., 0·105 grm. =5·54 per cent. water; the calculated quantity for 2 equivs. of water is 5·57 per cent.

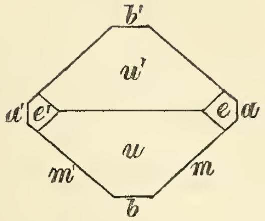
Double Chloride of Mercury and Sparteine.

When a solution of hydrochlorate of sparteine was added to a tolerably concentrated solution of corrosive sublimate, a white crystalline precipitate was immediately produced. This was collected on a filter, washed, and then dissolved in dilute hydrochloric acid. On the cooling of the solution, the double chloride crystallized in right rhombic prisms of considerable size and very high lustre. Through the kindness of Professor W. H. Miller of Cambridge, to whom I have been often indebted for similar obligations, I am enabled to subjoin an exact figure of these crystals, together with the measurements of their angles.

Bichloride of Platinum and Sparteine.

Prismatic:—Symbols of the simple forms,—*a* 100, *b* 010, *u* 011, *e* 101, *m* 110.
Angles between normals to the faces,—

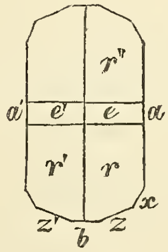
	°	′
ab	90	0
ub	37	18
uu′	105	24
ea	41	6
ee′	97	48
ma	48	52
mb	41	8
mm′	82	16



Double Mercurial Chloride of Sparteine.

Prismatic:—Symbols of the simple forms,—*a* 100, *b* 001, *e* 101, *x* 210, *z* 120, *r* 111.
The angles between normals to the faces are,—

	°	′
ba	90	0
za	65	39
xa	28	55
zz	48	42
ea	62	35
ee′	54	50
ra	65	46
rb	63	3
re	26	57
rr′	48	28
rr″	53	54
r′r″	75	24



Cleavage:—*a*, very perfect and easily obtained.

The faces *b*, *e*, *x* are very narrow, and are usually altogether wanting.

This salt was nearly insoluble both in water and in spirits of wine, but its solubility in these liquids was greatly increased by the addition of hydrochloric acid. The salt was first dried *in vacuo*, and did not lose any additional weight though heated afterwards to 212° FAHR. The amount of hydrogen, it will be seen, is slightly in excess; this arises from a small quantity of metallic mercury having sublimed into the chloride of calcium tube.

I. 0·785 grm. salt gave 0·3105 sulphuret of mercury =0·2676 Hg.

II. 0·806 grm. salt gave 0·2750 sulphuret of mercury =0·275 Hg.

0·553 grm. salt gave 0·624 carbonic acid and 0·262 water.

0·7145 grm. salt gave 0·7000 Ag Cl=0·1731 Cl=24·22 per cent. chlorine.

	Calculated numbers.		I.	II.
15 C	1125·0	31·14	30·77	
14 H	175·0	4·84	5·26	
N	175·2	4·87		
Hg	1250·9	34·62	34·08	34·11
2 Cl	886·4	24·53	24·22	
	3612·5			

The formula of this salt, therefore, is $C_{15}\ H_{13}\ N,\ H\ Cl,\ Hg\ Cl$.

When hydrochlorate of sparteine is added to the solution of bichloride of gold, a double gold salt is produced. It is but slightly soluble either in water or spirits of wine, but it readily dissolves in hot hydrochloric acid, out of which it crystallizes in shining yellow scales. When sparteine is added to a solution of chloride of copper, a green coloured precipitate is produced, which contains sparteine, and is probably a double salt. Similar combinations are also formed with both neutral and basic acetate of lead.

Sparteine possesses pretty powerful narcotic properties. When a single drop of it dissolved in acetic acid was administered to a rabbit, it immediately became exceedingly excited, and was thrown into a state resembling intoxication. This lasted five or six hours, and during a considerable portion of the time the rabbit remained in a profound sleep, from which it could with difficulty be roused. A similar dose produced the same effects upon a small dog. When four grains of the base were administered to a full-grown rabbit, violent excitement was at first produced; the animal, however, soon fell into a comatose state and expired in the course of three hours, but without exhibiting any violent convulsions. Sparteine appears therefore to be a tolerably strong narcotic poison, though certainly very inferior in this respect to either nicotine or coniine. Though the narcotic effects of broom are not noticed, so far as I am aware, by any medical writer, they have long been familiar to the peasantry. Thus shepherds have observed that, during snow storms, when their sheep were compelled to eat the tops of broom for subsistence, they were apt to become excited and stupified, so that they not unfrequently left their shelter, and, wandering over the snow, they soon fell asleep, and if neglected not unfrequently perished.

Scoparine, as I already mentioned, acts as a powerful diuretic; the dose for a grown-up person being from five to six grains repeated three times successively at intervals of four hours. It begins to operate in about twelve hours, and the amount of the urine is considerably more than doubled*. It is plain therefore that in employing a decoction of broom tops, as has hitherto been the practice, the patient is subjected to the narcotic influence of the sparteine as well as to the diuretic effects of the scoparine, a result which in general is not likely to be desirable.

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* I am indebted for the preceding experiments on the physiological effects of sparteine and scoparine, to my friend Dr. Arthur Mitchell of Glasgow, who kindly undertook them at my request.

I do not however think it is at all necessary to employ chemically pure scoparine for medical purposes. If a decoction of broom is evaporated to dryness on the water-bath, then treated with a little dilute hydrochloric acid, the mixture thrown upon a filter and washed with a small quantity of cold water, almost the whole of the sparteine will be removed, and the dark green gelatinous mass remaining on the filter will be found to possess the diuretic, without the narcotic properties of the plant.

I have already mentioned that the first quantity of the broom employed in this investigation was grown on sandy ground, freely exposed to the sun and air. A decoction was also made from a second quantity of very tall broom from 5 to 6 feet in height, which grew in a shady copse in the neighbourhood of Lanark. Its decoction had only a slightly bitter taste, and it did not yield more than one-fourth so much either scoparine or sparteine as the first quantity of broom had done; though the botanical properties of both plants were precisely the same.

This observation may perhaps help to explain the somewhat discordant results which eminent medical practitioners have experienced in regard to the diuretic effects of broom,—sometimes it having acted powerfully, while at others it appeared to be ineffective. Now, may not this have arisen from the circumstance that they had sometimes employed broom which had grown in a favourable, and sometimes that which had grown in a disadvantageous situation, and which therefore varied exceedingly in its medical properties?

Glasgow, November 16, 1850.

XVIII. *On Rubian and its Products of Decomposition.* *By* Edward Schunck, *F.R.S.*

Received January 9,—Read February 13, 1851.

PART I.

Among the many discussions to which the subject of madder has given rise among chemists, there is none which is calculated to excite so much interest as that concerning the state in which the colouring matter originally exists in this root, and there is no part of this extensive subject which is at the same time involved in such obscurity. It is a well-known fact that the madder root is not well adapted for the purposes of dyeing until it has attained a growth of from eighteen months to three years, and that after being gathered and dried it gradually improves for several years, after which it again deteriorates. During the time when left to itself, especially if in a state of powder, it increases in weight and bulk, in consequence probably of absorption of moisture from the air, and some chemical change is effected, which, though not attended by any striking phenomena, is sufficiently well indicated by its results. There are few chemical investigations that have thrown any light on the nature of the process which takes place during this lapse of time, and in fact most of the attempts to do so have merely consisted of arguments based on analogy. It has been surmised that the process is one of oxidation, and that the access of atmospheric air is consequently necessary. We are indeed acquainted with cases, in which substances of well-defined character and perfectly colourless, as for instance orcine and hematoxyline, are converted by the action of oxygen, or oxygen and alkalies combined, into true colouring matters. A more general supposition is, that the process is one of fermentation, attended perhaps by oxidation, and in confirmation of this view the formation of indigo-blue from a colourless plant, by a process which has all the characters of one of fermentation, may be adduced. What the substance is however on which this process of oxidation or fermentation takes effect, what the products are which are formed by it, whether indeed the change is completed as soon as the madder has reached the point when it is best adapted for dyeing, or whether further changes take place when it is mixed with water and the temperature raised during the process of dyeing, are questions which have never been satisfactorily answered, if answered at all. It has indeed been suspected by several chemists, that there exists originally some substance in madder, which by the action of fermentation or oxidation is decomposed and gives rise by its decomposition to the various substances endowed either with a red or yellow colour, which have been discovered during the chemical investigations of this root. That several of these substances are merely mixtures, and some of them in the main identical, has been satisfactorily proved by late investigators. But there still remain a number, which, though extremely similar, have properties sufficiently marked to entitle them to be considered as distinct.

In my papers on the colouring matters of madder[*], I have described four substances derived from madder, only one of which is a true colouring matter, but all of them capable, under certain circumstances, as for instance in combination with alkalies, of developing red or purple colours of various intensity. To seek for a common origin for these various bodies so similar to one another and yet distinct, is very natural, and the discovery of it no improbable achievement.

Persoz[†] asserts the probability of this view in the following words:—"We may hence venture to conclude that the colouring matters which we extract from fabrics dyed with madder, as well as the alizarine which is obtained by submitting the products derived from madder to sublimation, do not exist ready formed in this root, and are only products derived from another substance which has not yet been isolated..... From numerous experiments which I have made on this subject, it follows that the colouring matter of madder may be compared, in respect to the derivatives to which it gives rise, to tannin, so that I do not despair of being able, as far as regards their metamorphoses, to establish a parallel between the products derived from madder and those obtained from tannin. If it should be possible to confer on the former that tendency to assume regular forms with which the latter are endowed, the separation of the proximate colouring or colour-giving (*colorable*) matters of madder will be easy, and it will thus be possible to establish their elementary composition and thence their relation to one another."

To Mr. J. Higgin is due the merit of having first called attention to the fact, that important changes take place during the process of dyeing with madder, which can only be explained by supposing that an actual formation of colouring matter takes place during the process. In his paper 'On the Colouring Matters of Madder[‡],' Mr. Higgin has detailed his experiments on that peculiar substance discovered in madder by Kuhlmann and called by him *Xanthine*. I have shown, on a former occasion, that the xanthine of Kuhlmann and other investigators is not a pure substance, but a mixture of two distinct substances. This fact however does not affect the correctness of Mr. Higgin's conclusions, the general accuracy of which I shall have great pleasure in confirming in the course of this paper. The presence of xanthine is easily ascertained by the deep yellow colour and intensely bitter taste which it communicates to cold water. Guided by these two tests, Mr. Higgin arrived at the conclusion, that in an infusion of madder, made with cold or tepid water, when left to itself, or more rapidly when heated to 120° or 130° Fahr., the xanthine gradually disappears and there is formed a gelatinous or flocculent substance, which possesses all the tinctorial power originally belonging to the infusion, while the liquid has lost all trace of any such power, and that as alizarine is the only substance contained in madder capable of dyeing, the xanthine must, during this process, have been changed into alizarine. Mr. Higgin found that this process is completely arrested by heating the infusion to the boiling-point, or by adding alcohol, acids or acid salts to it, and hence he concludes that the decomposition of the xanthine is caused by the action of a peculiar ferment contained in madder, and which is extracted together with xanthine by cold water. Mr. Higgin did not however succeed in converting his xanthine into alizarine or effecting any change in it by means of fermentation, in consequence, as he supposed, of not being able to obtain the exciting substance in a soluble and consequently active condition. His inferences were all derived from experiments made by either removing from an extract of madder the xanthine contained in it, or by adding to it an additional quantity of that substance, and then ascertaining the effects produced by dyeing in the usual way with liquids thus artificially prepared. By the action of sulphuric acid on xanthine, Mr. Higgin obtained a dark brown powder, which he seems to consider as devoid of any tinctorial power.

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[*] See Reports of the British Association for 1847 and 1848.

[†] Traité de l'Impression des Tissus, t. i. p. 501.

[‡] Philosophical Magazine for Oct. 1848.

A very simple experiment suffices to prove that madder, in its dry state, contains very little, if any alizarine ready-formed. If an extract of madder be made with cold water, it will be found that the brownish-yellow liquid thus obtained when gradually heated will dye as well and as strongly as the madder from which it has been prepared. Now if the colouring matter were originally present in the form of alizarine, this could not take place, since alizarine is almost insoluble in cold water; and in employing it for the purpose of dyeing, it is necessary to dissolve it in warm or boiling water before it begins to exert any effect, as is plainly seen in the case of garancine, which contains alizarine ready-formed. Nor is there much colouring matter left behind in the madder after extraction with cold water, for after converting the residue in the usual manner into garancine by means of sulphuric acid, it is found to be capable of dyeing only very slightly. Nay more, if madder be extracted with hot water instead of cold, I have found the residue to give a garancine which dyed darker colours than that obtained from the residue of an equal weight of madder extracted with cold water, so that it appears that the colour-producing substance is more completely removed by cold than by hot water. If an extract of madder with cold water be left to stand, there is formed in it, as Mr. Higgin has shown, a flocculent substance, while the liquid loses its bitter taste, part of its yellow colour and the whole of its power of dyeing, which is now found to reside in its whole extent in the flocculent substance. This change takes place equally well with or without the access of atmospheric air.

By adding a variety of substances to an extract of madder with cold water, I was enabled to ascertain under what circumstances and by what means the tinctorial power of the liquid is destroyed, and consequently what is the general character of the substance or substances to which it is due. I found that by adding sulphuric or muriatic acid to the extract and heating, the liquid, after neutralization of the acid, was no longer capable of dyeing. The tinctorial power was also destroyed by the addition of hydrate of alumina, magnesia, protoxide of tin and various metallic oxides, but not by carbonate of lime or carbonate of lead. In all cases in which the property of dyeing in the extract was destroyed, I invariably found that its bitter taste and bright yellow colour were lost. Now in my former papers on this subject, I have shown that the intensely bitter taste of madder and its extracts is due to a peculiar substance, to which I have given the name of *Rubian*; and as it appeared from these preliminary experiments that this substance, though itself no colouring matter, is in some way concerned in the changes whereby a formation of colouring matter is induced in aqueous extracts of madder, I proposed to myself to examine its properties and products of decomposition more in detail than I had hitherto done.

The first step necessary to be taken for the attainment of this object, was of course to find a method of procuring this substance in quantities sufficiently large for the purposes of examination. I was at the commencement however far from appreciating the difficulties with which its preparation in a state of purity is attended. The process which I had formerly described, by precipitation with sulphuric acid, is not well adapted to the purpose, since rubian in a state of perfect purity is not precipitated by sulphuric acid, besides which it is easily decomposed by an excess of that acid. Neither is it precipitated by any metallic salt, with the exception of basic acetate of lead, which, from the circumstance of its precipitating also other substances from the extract, is not applicable to the purpose. It is decomposed by alkalies and alkaline earths. Even bicarbonate of lime exerts a decomposing effect on it in conjunction with the oxygen of the atmosphere. These substances must therefore be discarded in its preparation. Besides its great tendency to decomposition, there is another circumstance which presents obstacles to almost all attempts to prepare rubian in a state of purity. There is no investigation of madder which does not make mention of a substance, which when its solution in water is mixed with sulphuric or muriatic acid and boiled, gives rise to the formation of a dark green powder. To this substance, which possesses no bitter taste, and is in fact devoid of any characteristic property except the one mentioned, I have restricted the name of xanthine. The xanthine of most other chemists is however a mixture of rubian with this substance, and possesses therefore the bitter taste of the former, while showing the characteristic behaviour of the latter towards acids. To avoid confusion, I shall no longer employ the name of xanthine, and I shall call the substance which gives the green powder with acids *Chlorogenine*. Now these two substances, though of very different nature, behave similarly towards many reagents. If, for instance, basic acetate of lead be added to a watery extract of madder, according to the method proposed by Berzelius for the preparation of xanthine, and adopted with a slight modification by Mr. Higgin, there is produced a red precipitate, which after being washed and decomposed with sulphuretted hydrogen or sulphuric acid, gives a solution containing rubian; but the presence of chlorogenine is also indicated by its turning dark green when boiled with the addition of sulphuric or muriatic acid. Hence it follows that chlorogenine, though it is not thrown down by basic acetate of lead when present alone in a solution, is still in part precipitated thereby when rubian is present at the same time. The same circumstance takes place with other precipitants.

After numerous experiments I discovered a property of rubian, which is perhaps more characteristic of it than any other, and that is the remarkable attraction which is manifested by it towards all substances of a porous or finely-divided nature, and it was this property by means of which I was at length enabled to obtain it in a state of purity. If to a watery extract of madder a quantity of protochloride of tin be added, a light purple lake is precipitated. Most of the rubian remains in the solution, which still retains its yellow colour and bitter taste. If, however, after filtering, sulphuretted hydrogen be passed through it, then, provided the quantity of tin still in solution be sufficiently large, the sulphuret of tin, at the moment of precipitation, carries down the whole of the rubian, and the solution loses its bitter taste and the greater part of its yellow colour. The whole of the chlorogenine remains in solution, and may easily be detected in the filtered liquid by means of acids. If the sulphuret of tin, after being collected on a filter and well washed with cold water until the percolating liquid no longer gives a green colour on being mixed with acid and boiled, be treated with boiling alcohol, a yellow solution is obtained, which on evaporation gives pure rubian, without any admixture of chlorogenine, in the shape of a dark yellow, brittle substance. The same effect is produced by sulphuret of lead. If sugar of lead be added to an extract of madder, a dark reddish-brown precipitate falls, the liquid still containing the rubian of the extract, as seen by its deep yellow colour and bitter taste. If sulphuretted hydrogen be now passed through the filtered liquid, a great part of the rubian goes down with the sulphuret of lead, and may again be separated from it by means of boiling alcohol. That this action of the sulphurets on rubian depends very much on their state of division, and is therefore mainly of a mechanical, and not chemical nature, is proved by the fact, that the sulphurets of tin and lead, if prepared by precipitation from solutions of salts in water, and then allowed to settle and repose for some time before being added to a watery extract of madder, remove far less rubian from it than they do, if they are formed in the extract itself, whence it follows that it is only in the minute state of division, in which they exist at the moment of precipitation, before the particles have time to cohere, that these sulphurets exert any great attraction for rubian. That they do however combine with some portion of the rubian is proved by the fact, that the power of dyeing in an extract of madder is very much diminished by adding to it sulphuret of tin or lead, previously precipitated. Of the two sulphurets, the sulphuret of tin, which is always precipitated in much finer particles than the other, is by far the most powerful absorbent of rubian. If equivalent quantities of protochloride of tin and acetate of lead be added to equal measures of watery extract of madder, the sulphuret of tin from the former absorbs at least twice as much rubian as the sulphuret of lead from the latter. Sulphuret of copper acts differently. If sulphate of copper be added to the extract of madder, a precipitate is produced, as in the case of almost all metallic salts. On passing sulphuretted hydrogen through the filtered liquid, the latter becomes dark brown, but no sulphuret of copper is precipitated.

This attraction of surface exerted towards rubian by bodies in a state of minute division is not confined to metallic sulphurets. There are few bodies which exceed animal charcoal in porosity, or which, in other words, possess for the same bulk a greater extent of surface. I found accordingly that animal charcoal exhibits a still greater attraction for rubian than even sulphuret of tin. A very small quantity of animal charcoal is sufficient to deprive an aqueous extract of madder of its bitter taste and of its tinctorial power. Lamp-black acts in the same manner, though much less powerfully. Wood charcoal however has no absorbent effect whatever on rubian. All these substances attract rubian alone, leaving the other substances contained in the extract, such as chlorogenine, sugar and pectine, untouched. By means of boiling alcohol part of the rubian in combination with them is again removed, and thus an easy and efficient means is given of obtaining rubian in a state of purity. Of these substances none is so well adapted in all respects as animal charcoal. In employing sulphuret of tin, which is the only one that at all approaches it in efficiency, much time is consumed in the process of filtration and washing. Besides this, I found that on operating with it on a large scale, the rubian obtained was in great part decomposed on evaporating the alcoholic solution, just as if it contained a quantity of acid; and even on treating a portion of the solution with carbonate of lime, for the purpose of neutralizing any free acid that might be present, and evaporating over sulphuric acid at the ordinary temperature, there was obtained a deliquescent mass, which, as further experiments showed, could not be considered as pure rubian. After many trials I at length adopted the following method of preparation, which surpasses all others in facility and certainty of execution.

A weighed quantity of madder* being placed on a piece of calico or fine canvas stretched on a wooden frame, boiling water, which is preferable to cold water, as all decomposition of the rubian by means of fermentation is thereby arrested, is poured on it, four quarts of the latter being sufficient for every pound of madder. A dark yellowish-brown liquor is obtained, to which there is added, while hot, for every pound of madder taken 1 ounce of animal charcoal, prepared in the usual way from bones. This proportion of charcoal should not be exceeded, for if an excess of it be taken, as for instance 1½ ounce for every pound of madder, the whole of the rubian is certainly removed from the solution; but on afterwards treating the charcoal with alcohol very little rubian is dissolved, from which it appears that the solvent power of the alcohol only overcomes the attraction of the charcoal for rubian in part. In using the first proportion, part of the bitter taste of the extract remains, showing that the rubian is in excess. The liquid being well stirred with the charcoal, the latter is allowed to settle, which it does in a very short time, and the liquid, which still retains a brown colour, is decanted. The charcoal is then placed on a piece of calico or on a paper filter and washed with cold water, until the percolating liquid, when mixed with muriatic acid and boiled, no longer acquires a green colour, which is a sign that the chlorogenine is removed. These operations occupy a very short time, in consequence of the rapidity with which the animal charcoal may be washed. The animal charcoal is now treated with boiling alcohol, which is filtered boiling hot, and the treatment is repeated until it no longer communicates to the alcohol any yellow colour. The rubian obtained by evaporating the alcoholic liquid is however impure; it contains a considerable quantity of chlorogenine, however carefully the charcoal may have been washed with water, and consequently gives a green powder when treated with boiling sulphuric or muriatic acid. This proceeds from the circumstance that fresh animal charcoal, when used in the preparation of rubian, invariably takes up, besides rubian, a quantity of chlorogenine, which is not removable by cold water, but which afterwards dissolves together with the rubian in boiling alcohol. Nevertheless, on using the charcoal which has been once employed, after treatment with alcohol, a second time for the same purpose, it seems to take up rubian alone and no chlorogenine, notwithstanding its being, as might be supposed, in the same condition for again absorbing the latter as it was in the first instance. At all events, the alcohol dissolves only rubian out of the charcoal, when it is used a second time; and if the alcohol should still contain chlorogenine, there will certainly not be a trace of the latter in the alcoholic solution, when the charcoal is used for the third time. That the attraction of the charcoal for rubian is not diminished after it has been once used and then exhausted with alcohol, however indifferent it then becomes towards chlorogenine, is proved by the fact that far more rubian is obtained when the charcoal is employed for the second time than in the first instance. If the animal charcoal, after being once used and exhausted, be heated red-hot so as to destroy all organic matter contained in it, it again behaves towards the two substances in the same manner as in the first instance, that is, it absorbs a mixture of rubian and chlorogenine. It is therefore advisable to reject the rubian which is obtained from the charcoal that has been used for the first time*. If a small portion of the alcohol with which the charcoal has been treated no longer gives a green colour when mixed with acid and boiled, but remains of a pure yellow, it is distilled or evaporated. During evaporation a small quantity of a dark brown flocculent substance is deposited, which is separated by filtration. The solution now contains, besides rubian, another substance in small quantity, which is a product of decomposition of rubian itself, and is probably formed by the application of too great a heat in the process of drying the madder. There are two ways in which this substance may be removed. The first consists in adding to the solution sugar of lead, which precipitates it in dark reddish-brown flocks. These being separated by filtration, the rubian is precipitated by means of basic acetate of lead, and the light red compound or lake, after being washed with alcohol to remove all excess of lead salt, is decomposed either with sulphuretted hydrogen, or better still with sulphuric acid, the excess of the latter being removed by carbonate of lead. The other method, which is more expeditious, consists in adding sulphuric acid to the cold solution, after the greatest part of the alcohol has been evaporated. The sulphuric acid completely decomposes the foreign substance, provided a sufficient quantity is employed, and converts it into a substance which renders the solution milky, and then falls in the shape of brown resin-like drops. The sulphuric acid being neutralized with carbonate of lead, the filtered solution, which is yellow and now contains pure rubian, is evaporated to dryness. It is necessary to employ carbonate of lead, and not carbonate of baryta, for the neutralization of the sulphuric acid in both cases ; for if carbonate of baryta be used, the bicarbonate of baryta which is usually formed, even if present only in small quantity, causes part of the rubian to undergo decomposition. In evaporating the solution of rubian, care must be taken not to employ too great a heat when the evaporation approaches to a conclusion. The ordinary heat of a sand-bath is sufficient to decompose rubian in great part, especially if a large quantity of the substance be present. It is therefore advisable, when the solution is nearly evaporated, to complete the evaporation either in a water-bath or in a moderately warm place. The free access of atmospheric air need not be feared, as rubian is not thereby decomposed, unless some other substance be present at the same time. The quantity of rubian which I have obtained, according to this method of preparation, amounts to about 1000 grs. from 1 cwt. of madder. It may be mentioned that the method of preparing rubian, as above described, by means of animal charcoal and alcohol, is not new in principle. LEBOURDAIS[*] has proposed the same method for the preparation of several vegetable substances, such as colocynthine, strychnine, quinine, &c.

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* Avignon madder, of the variety called *Rosa*, was the kind used.

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* This impure rubian cannot be purified by means of basic acetate of lead, since when rubian is present in a solution together with chlorogenine, the latter is, though not entirely, still in great part precipitated together with the rubian by that salt.

Properties of Rubian.—When prepared according to the method just described, rubian is obtained as a hard, dry, brittle, shining, perfectly uncrystalline substance, similar in appearance to gum or dried varnish. It is not in the least deliquescent, as xanthine is described to be. In thin layers it is perfectly transparent and of a beautiful dark yellow colour. In large masses it appears dark brown. It is very soluble in water and alcohol, more so in the former than the latter, but insoluble in ether, which precipitates it from its alcoholic solution in brown drops. Its solutions have an intensely bitter taste. When it is pure, its solution in water gives no precipitates with the mineral or organic acids, nor with salts of the alkalies or alkaline earths.

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[*] On the Nature and Preparation of the Active Principles of Plants, Annal. de Chim. et de Phys. 3^{me} ser. t. xxiv. p. 58.

Acetate of alumina, alum, protacetate and peracetate of iron, acetate of zinc, neutral and basic acetate of copper, acetate of lead, nitrate of silver, perchloride of tin, protonitrate of mercury, perchloride of mercury and chloride of gold produce no precipitate whatever in a watery solution of pure rubian, nor does any reaction take place, except a darkening of the solution in the case of some of these salts. If the rubian be impure, which is always the case when the solution has been incautiously evaporated and the rubian has been exposed to too great a heat after evaporation, then its solution, though it does not differ in appearance from one of pure rubian, when mixed with any mineral or organic acid, even acetic acid, or the salts of the alkalies or alkaline earths, is rendered milky, and a quantity of dark brown transparent resinous drops, mixed with yellow flocks, are deposited. These drops, in the case of the salts, consist merely of a substance insoluble in saline liquids, which dissolves again in pure water; but in the case of acids, they are, though similar in appearance, a product of decomposition of the latter substance, and do not redissolve in pure water. Sugar of lead gives, in a solution of impure rubian, a dark reddish-brown precipitate. Most metallic salts also give precipitates, consisting either of the substance itself which accompanies the rubian, or of compounds of this substance, with the respective metallic oxides. I shall return to these reactions when I come to treat of the action of heat on rubian. Basic acetate of lead gives a copious light red precipitate in a solution of pure rubian, the solution becoming colourless. This is the only definite compound of rubian with a base that I am acquainted with. Concentrated sulphuric acid dissolves rubian with a blood-red colour; on boiling the solution it becomes black and disengages sulphurous acid gas in abundance, after which water precipitates a black carbonaceous mass. If sulphuric acid be added to a watery solution of rubian, and the mixture be boiled, the solution, if dilute, becomes opalescent, and on cooling a quantity of light yellow flocks are deposited; and if the solution was concentrated, these are formed in such abundance on cooling as to render the liquid thick. If these flocks exhibit the least tinge of green, the presence of chlorogenine is indicated. Muriatic acid acts in precisely the same manner. Nitric acid produces in the cold no effect in a solution of rubian, but on boiling a disengagement of nitrous acid takes place, the liquid becomes light yellow, and now contains the acid which I called in my former papers alizaric acid, and which Laurent and Gerhardt consider as identical with naphthalic acid. Phosphoric, oxalic, tartaric and acetic acids produce no effect on the solution, even on boiling for some time. When a stream of chlorine gas is passed through a watery solution of rubian, the solution immediately becomes milky and begins to deposit a lemon-yellow powder, into which, on continuing the action, the whole of the rubian is converted, the liquid becoming colourless. Caustic soda turns the colour of the solution from yellow to blood-red, and on neutralizing the alkali with acid, a clear yellow solution is again obtained. By boiling the solution to which the soda has been added, the colour changes from blood-red to purple; and on now supersaturating the alkali with acid, a reddish yellow precipitate falls, while the supernatant liquid becomes almost colourless. Ammonia changes the colour of a solution of rubian to blood-red; the colour is not changed by boiling; and by supersaturating the ammonia with acid either before or after boiling, no precipitate is formed. Lime and baryta water give dark red precipitates in a solution of rubian, which are soluble in pure water, forming dark red solutions. Magnesia turns the solution dark red; the solution contains magnesia. The carbonates of lime and baryta produce no perceptible effect on a solution of rubian; they do not change its colour, nor do they take up any rubian. Hydrate of alumina, when placed in a solution of rubian, acquires a brownish-yellow colour. If sufficient alumina be taken, the liquid is rendered almost colourless. Hydrated peroxide of iron acts in a similar manner. Oxide of copper also removes most of the rubian from its solution. Alkaline solutions of rubian do not reduce the oxides of silver and copper on the addition of salts of these oxides, but they reduce salts of gold to the metallic state. When heated on platinum foil, rubian melts, swells up very much, burns with a flame and gives a carbonaceous residue, which does not entirely disappear on being further heated, but leaves a quantity of ash. When heated gradually in a tube it begins to undergo decomposition, accompanied by loss of water at a temperature of about 130° C., and is converted into another substance, which I shall describe further on. When heated to a still higher degree in a tube or retort, it gives fumes of an orange colour, which condense on the colder parts of the vessel to a crystalline mass, consisting chiefly of alizarine.

Rubian cannot be considered as a colouring matter in the ordinary sense of the word. It imparts hardly any colour to mordanted cloth, when an attempt is made to dye with it in the usual way, the alumina mordant only acquiring a slight orange, the iron mordant a light brown colour.

Composition of Rubian.—In determining the composition of rubian, I found it necessary to take into consideration the fact of its leaving when burnt a considerable quantity of ash. This ash consists almost entirely of carbonate of lime. The amount of ash is not uniform in different specimens; it is greatest when the rubian has been purified by means of sulphuric acid, but I have never been able to obtain it in a state in which it burns without any residue. Even after being precipitated with basic acetate of lead and again separated from the oxide of lead, rubian leaves some ash on being burnt, so that it appears as if the lime which it contains were an essential constituent, or at all events, that it follows it into the lead compound, from which it cannot be removed by means of water or alcohol.

The following results were obtained on analysis:—

I. 0·3880 grm. rubian, which had been purified by means of sulphuric acid, dried at 100° C., gave, when burnt with oxide of copper, 0·7210 carbonic acid and 0·1745 water.

II. 0·4780 grm. of the same preparation, burnt with oxide of copper, gave 0·8865 carbonic acid and 0·2180 water.

III. 0·4755 grm. of the same preparation, burnt with oxide of copper, gave 0·8835 carbonic acid and 0·2180 water.

0·1690 grm., on being incinerated, left 0·0130 grm. of ash=7·69 per cent.

IV. 0·3910 grm. rubian, purified by means of acetate and basic acetate of lead, burnt with chromate of lead, gave 0·7455 carbonic acid and 0·1880 water.

0·4050 grm. of this preparation left 0·0215 grm. of ash=5·30 per cent.

V. 0·4235 grm. rubian, purified in the same way as I. and burnt with chromate of lead, gave 0·7890 carbonic acid and 0·2020 water.

0·6400 grm. of this preparation left 0·0465 ash=7·26 per cent.

VI. 0·4390 grm. rubian, purified in the same way as IV., burnt with chromate of lead, gave 0·8370 carbonic acid and 0·2120 water.

0·8400 grm. of this preparation left 0·0440 ash=5·23 per cent.

After making the necessary corrections for the ash, these numbers correspond in 100 parts to—

	I.	II.	III.	IV.	V.	VI.
Carbon	54·89	54·79	54·89	54·90	54·78	54·84
Hydrogen . . .	5·41	5·48	5·51	5·64	5·71	5·66
Oxygen	39·70	39·73	39·60	39·46	39·51	39·50

Rubian contains no nitrogen. On burning it with oxide of copper and collecting the gas over mercury, I found the latter to be entirely absorbed by caustic alkali. When burnt with lime and soda, only a minute trace of chloride of platinum and ammonium was obtained. The statement contained in my former paper, which was made at a time when I had not obtained rubian in a state of absolute purity, that nitrogen is one of its constituents, must therefore be corrected.

From the above analyses the following composition may be deduced:—

	Eqs.		Calculated.
Carbon	56	336	55·08
Hydrogen	34	34	5·57
Oxygen	30	240	39·35
		610	100·00

The compound with oxide of lead, which was the only one that could be employed for the determination of the atomic weight, was prepared by dissolving rubian in alcohol, adding acetate of lead, precipitating with a little ammonia, taking care to leave an excess of rubian, and washing with alcohol. If it be prepared by precipitation from a watery solution by means of basic acetate of lead, great difficulties are experienced in the course of filtration; the liquid begins to run through slowly, the precipitate becomes somewhat mucilaginous and adheres to the paper, and sometimes even it seems to be decomposed and no longer gives unchanged rubian, but a dark brown viscid substance. Its analysis gave the following results:—

I. 0·3670 grm., dried at 100° C. and burnt with chromate of lead, gave 0·3520 carbonic acid and 0·0875 water.

0·3360 grm. gave 0·2390 sulphate of lead.

II. 0·4440 grm. of another preparation, burnt with chromate of lead, gave 0·4190 carbonic acid and 0·1115 water.

0·4320 grm. gave 0·3100 sulphate of lead.

III. 0·4635 grm. of the same preparation as the last gave 0·4450 carbonic acid and 0·1050 water.

0·5405 grm. gave 0·3880 sulphate of lead.

These numbers lead to the following composition:—

	Eqs.		Calculated.	I.	II.	III.
Carbon	56	336	26·25	26·15	25·73	26·18
Hydrogen	34	34	2·65	2·64	2·87	2·51
Oxygen	30	240	18·76	18·89	18·62	18·51
Oxide of lead . . .	6	670	52·34	52·32	52·78	52·80
		1280	100·00	100·00	100·00	100·00

Hence it appears that oxide of lead in combining with rubian does not replace any basic water, as is usually the case.

It may easily be conceived that a body so readily decomposed as rubian gives a number of different products of decomposition. It is decomposed by acids, alkalies, chlorine, heat and ferments; and I shall now proceed to describe the products of decomposition to which these various reagents give rise.

Action of Sulphuric and Muriatic Acid on Rubian.—The action of these two acids is precisely the same; but for the purpose of studying it, it is better to employ sulphuric acid, as it is more easily removed again afterwards. On adding sulphuric acid in considerable quantity to a watery solution of rubian and boiling the liquid, no perceptible change takes place at first, except that the solution loses a little of its transparency and becomes slightly opalescent. If the solution was not very dilute, there begin to appear very soon a number of orange-coloured flocks. After boiling for some time and allowing to cool, these flocks are deposited in large quantities, and the liquid is now found to be much lighter in colour than before. After allowing to cool and filtering, the liquid, on being mixed with fresh acid and boiled again, often deposits on cooling a fresh quantity of these flocks. When after repeated boilings no more flocks separate on cooling, the process is completed. The last portions of rubian are usually more difficult to decompose than the first, and an additional quantity of acid is therefore necessary to effect their decomposition. The liquid retains to the last a light yellow colour. I shall return to it presently. The orange-coloured flocks are washed on the filter with cold water until all the acid is removed. They now consist of four different substances, three of which are bodies previously known, the fourth one which has not hitherto been observed. The three former are,—1st, *Alizarine*; 2ndly, the substance which in my former papers I have called *alpha-resin*, but to which I prefer giving the name of *Rubiretine*; 3rdly, the substance which I formerly termed *beta-resin*, but I shall now call *Verantine* from *Verantia*, the name applied to madder in the middle ages. The fourth substance I shall denominate *Rubianine*.

The presence of alizarine in this mixture is indicated by the dark and beautiful colours which are produced when it is employed for dyeing a piece of mordanted cloth, and which contrast forcibly with the faint and dull tints produced by rubian. It may also easily be separated from the other substances by dissolving the mixture in alcohol, adding hydrate of alumina to the solution, filtering, treating the alumina compound repeatedly with a solution of carbonate of potash or soda, until nothing more is dissolved by the latter, decomposing the alumina compound with acid, and dissolving the residue in alcohol, when on evaporating the latter crystals of alizarine with its usual characters are obtained. In order however to obviate all objections which might arise from the use of alkalies in regard to the effect which the latter might be supposed to have in causing the formation of the alizarine, I determined if possible to use acids and salts only in the separation of the substances mentioned above. Of the four substances contained in the orange-coloured flocks, two, viz. alizarine and rubianine, are soluble in boiling water, and may thereby be separated from the two others which are insoluble in water. This method of separation is however tedious, on account of the sparing solubility of alizarine and rubianine in boiling water. I therefore prefer using the following method. The orange-coloured flocks containing the four substances are treated with boiling alcohol, in which they dissolve with a dark reddish-yellow colour. The alcohol is filtered boiling hot, and deposits on cooling a small quantity of yellow crystalline particles, consisting chiefly of rubianine. The treatment with alcohol is repeated as long as the latter acquires a dark yellow colour. The greatest part of the rubianine remains behind as a yellow or brownish-yellow crystalline mass, which is treated repeatedly with boiling alcohol, in which the whole at last dissolves, the greatest part again separating on the solution cooling, either in yellow needles or as a brownish-yellow crystalline mass. If its colour is not a pure yellow, or if it is imperfectly crystallized, it contains verantine and must be purified. For this purpose the whole of the mass which has been deposited on the alcohol cooling, after being collected on a filter, is again dissolved in boiling alcohol, and sugar of lead is added to the solution, by which means the verantine is precipitated in combination with oxide of lead, while the rubianine remains in solution and is again deposited, when the solution, after being filtered boiling hot, is allowed to cool, in long, lemon-yellow silky needles, which may be rendered perfectly pure by recrystallization. The compound of verantine and oxide of lead may be decomposed with sulphuric acid, and the verantine separated from the sulphate of lead by boiling alcohol. The alcoholic liquid from which the rubianine has been deposited contains the three other substances besides a portion of the rubianine. By adding acetate of alumina to it, the whole of the alizarine as well as a part of the verantine are precipitated, in combination with alumina, in the shape of a dark red powder, while the liquid retains a dark brownish-red colour. This precipitate, after being collected on a filter and washed with alcohol until the latter runs through colourless, is decomposed with muriatic acid, which dissolves the alumina, leaving behind red flocks consisting of alizarine and verantine. These flocks, after being filtered off and washed with water, are again dissolved in alcohol, to which is then added a solution of neutral acetate of copper. This instantly changes the colour of the liquid to a beautiful dark purple. The copper compound of alizarine remains dissolved, while the verantine is entirely precipitated, in combination with oxide of copper, as a dark reddish-brown powder. The dark purple liquid, after filtration and evaporation, leaves a purple mass of alizarine-oxide-of-copper, which is decomposed with muriatic acid. Yellow flocks, consisting of alizarine, remain behind, which after being washed with water are dissolved in alcohol. The alcoholic solution on evaporation gives crystals of alizarine, which may be purified by recrystallization. The compound of verantine with oxide of copper is decomposed with muriatic acid. The liquid filtered from the alumina compound of alizarine and verantine is evaporated to dryness, muriatic acid is added to the residue, which is placed on a filter and washed with cold water until all the acid and salts of alumina are removed. On being now treated with boiling water, a quantity of dark brown resinous drops sink to the bottom of the vessel and cohere into a semi-fused mass, while brownish-yellow flocks float in the water. The water is decanted from the mass at the bottom, carrying with it the flocks. This process is repeated with fresh quantities of water until no more flocks are carried away by it. The resinous mass at the bottom now consists principally of rubiretine. It may be purified by dissolving in cold alcohol, which leaves behind a quantity of verantine. The brownish-yellow flocks consist chiefly of verantine and rubianine; they are treated with boiling water, in which the rubianine dissolves, and from which it is again deposited, on filtering the water boiling hot and allowing to cool, in orange-coloured flocks. The process is repeated until the water dissolves nothing more. The orange-coloured flocks of rubianine are collected on a filter and dissolved in boiling alchohol, out of which the rubianine crystallizes on cooling in yellow needles. The mother-liquor is somewhat darker than a mere solution of rubianine would be. It contains a little alizarine and rubiretine, which may be separated by means of acetate of alumina, as before described. The verantine which is left behind by the boiling water is mixed with the other portions obtained from the lead and copper compounds, and the whole is dissolved in a small quantity of boiling alcohol, out of which the verantine is deposited on cooling as a dark reddish-brown or yellowish-brown powder, which may be purified by a second solution in alcohol.

These substances can, as may be supposed, be obtained without any difference in properties by adding sulphuric or muriatic acid to an extract of madder made with boiling water, boiling the liquid, and treating the dark green precipitate obtained in the same way as the orange-coloured flocks, from the decomposition of rubian. The dark green colour of the precipitate in this case proceeds from the decomposition of chlorogenine by the acid; the product of decomposition does not however in any way interfere, as it is insoluble in alcohol. It may be remarked, however, that very little rubianine is obtained in this manner, its place being supplied, from a cause which I shall mention hereafter, by rubiacine.

There still remains in the acid liquid filtered from the orange-coloured flocks, a substance which is an essential product of the action of acids on rubian. This liquid has, as I mentioned before, a light yellow colour. After neutralizing the acid with carbonate of lead it becomes almost colourless, while the carbonate of lead acquires a pink tinge. After filtration it is found to contain neither sulphuric acid nor lead; nor does it give any precipitate with neutral or basic acetate of lead, nor with alkalies, either before or after neutralization, unless it be boiled with an excess of the latter. This absence of reaction proves that no substance of a basic nature has been formed during the process. The liquid however contains a considerable quantity of an organic substance, which is obtained by carefully evaporating at the ordinary temperature over sulphuric acid. It is not advisable to evaporate with the assistance of heat, as the solution then becomes dark brown from the action of the air. After evaporation over sulphuric acid there is left at last a brownish-yellow, transparent syrup, having a sweetish taste, which I shall prove by its properties and composition to be a species of sugar.

I shall now describe more in detail the properties of the substances just mentioned.

Alizarine.—The alizarine obtained from the decomposition of rubian exhibits all the usual properties of this well-known substance. Its colour is dark yellow without any tinge of brown or red. The crystals possess a lustre which I have never seen equalled in this substance. Its analysis gave the following results:—

0·3200 grm. of the crystals, on being heated in the water-bath, lost 0·0580 grm. of water=18·12 per cent. According to the formula $C_{14} H_5 O_4 + 3HO$, they should lose 18·24 per cent.

0·2575 grm. of the dry substance, burnt with chromate of lead, gave 0·6550 carbonic acid and 0·0945 water.

These numbers lead to the following composition:—

	Eqs.		Calculated.	Found.
Carbon	14	84	69·42	69·37
Hydrogen	5	5	4·13	4·07
Oxygen	4	32	26·45	26·56
		121	100·00	100·00

0·1050 grm. of the lead compound, prepared by precipitating the alcoholic solution with sugar of lead, gave 0·0720 sulphate of lead, equivalent to 0·0529 oxide of lead

=50·44 per cent. The formula $C_{14}H_4O_3+PbO$ requires 49·90 per cent. oxide of lead.

The formula here given is the same to which I was led by my former experiments, and it now receives a new confirmation from the relation in which it stands to that of rubian.

The formation of alizarine from rubian admits of a very easy explanation. By simply losing 14 equivs. of water, 1 equiv. of rubian is converted into 4 equivs. of alizarine, as the following equation shows:—

$$C_{56}H_{34}O_{30}=4(C_{14}H_5O_4)+14HO.$$

The action of sulphuric acid in the preparation of garancine from madder now becomes more intelligible. It consists simply, as far as the practical effect is concerned, in the conversion of rubian into alizarine.

MM. Wolff and Strecker, in a late paper 'On the Red Colouring Matters of Madder*,' have given another formula for alizarine, which they prefer on account of the relation in which they suppose this substance to stand to naphthaline. This formula is $C_{20}H_6O_6$, which requires in 100 parts—

Carbon	68·96
Hydrogen	3·45
Oxygen	27·59

In confirmation of this formula they adduce one analysis, in which they obtained from 0·0650 grm. alizarine 0·163 carbonic acid, equivalent to 68·4 per cent. If it be permitted to deduce any safe inference from the analysis of so small a quantity of substance, I should be inclined to say that the substance analysed was impure. Even when perfectly well crystallized, alizarine may contain an amount of impurity sufficient to affect its composition. This impurity generally consists of verantine. A large admixture of the latter substance entirely prevents alizarine from crystallizing, but a small quantity merely gives the crystals a brownish or reddish tinge. Alizarine can never be considered as perfectly pure unless it exhibits a pure dark yellow colour without admixture of red. In proof of this statement I may adduce the following experiments. In the course of my investigation I obtained from madder a specimen of alizarine in perfectly well-defined crystals, containing apparently no foreign substance, but having a brownish-red colour instead of the dark yellow characteristic of pure alizarine.

0·3530 grm. of these crystals, dried at 100° C., gave 0·8855 carbonic acid, equivalent to 68·41 per cent. of carbon.

The remainder of the substance was recrystallized from alcohol, and

0·2940 grm. now gave 0·7360 carbonic acid, equivalent to 68·27 per cent. of carbon.

On dissolving the rest in alcohol and adding to the solution acetate of copper, a dark reddish-brown precipitate of verantine-oxide-of-copper fell. From the dark

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[*] Ann. der Chem. u. Pharm., vol. lxxv. p. 1.

purple solution, after being treated in the manner before described, there were obtained some beautiful dark yellow crystals of alizarine, which on analysis yielded the following result:—

0·1270 grm., dried at 100° C., gave 0·3245 carbonic acid, equivalent to 69·68 per cent. of carbon.

It appears therefore that alizarine cannot be separated from the last portions of impurity by recrystallization merely.

Were the above formula the correct one, it would be difficult to account for the circumstance that the purer the substance the greater is the excess, not only of hydrogen, but also of carbon. An excess of 0·6 per cent. of hydrogen, as this formula would pre-suppose, is unusually large; an excess of 0·4 per cent. of carbon seldom or never obtained in the analysis of a pure substance. The most common impurity of alizarine is verantine; and since the latter contains, as I shall presently show, more oxygen for the same amount of carbon and hydrogen, it follows that if a portion of it be mixed with the alizarine, the amount of carbon and hydrogen in the latter will be reduced, and the composition will approximate to that given by Wolff and Strecker.

Again, if the correct formula for alizarine be $C_{20} H_6 O_6$, the formula of rubian must necessarily be $C_{20} H_{11} O_{11}$, which requires in 100 parts—

Carbon	54·79
Hydrogen	5·02
Oxygen	40·19

These numbers, as will be perceived, do not agree so well with those of the analyses as those corresponding to the formula which I have given above. The lead compound of rubian can, under this supposition, only be represented by the formula $6(C_{20} H_{11} O_{11})+13PbO$, which requires in 100 parts—

Carbon	26·03
Hydrogen	2·38
Oxygen	19·10
Oxide of lead	52·49

Here also it will be seen there is less accordance with the numbers found by experiment than in the case of the other formula. But besides this, the latter formula is of too complicated a nature to be received; I therefore consider the formula $C_{14} H_5 O_4$, or perhaps $C_{28} H_{10} O_8$, for alizarine to be as firmly established as it can be with the means at present at our command.

Verantine.—This substance coincides in most of its properties with the substance to which I formerly gave the name of the beta-resin of madder. When prepared according to the method above described, it is obtained in the shape of a reddish-brown powder, similar in colour to snuff or roasted coffee. It has the following properties. When heated on platinum-foil it melts and then burns away without leaving any residue. When heated in a glass tube it gives a small quantity of an oily sublimate without a trace of anything crystalline. When however it contains alizarine, as it very often does, it gives on being heated a crystalline sublimate consisting of the latter substance. It dissolves in concentrated sulphuric acid with a brown colour, and is reprecipitated by water in brown flocks. On heating the solution in concentrated sulphuric acid it becomes black, sulphurous acid is disengaged, and the substance is decomposed. Concentrated nitric acid dissolves it on boiling with a disengagement of nitrous acid, forming a yellow liquid, from which nothing separates on cooling. Dilute nitric acid does not affect it sensibly on boiling. It is almost insoluble in boiling water, but readily soluble in boiling alcohol with a dark brownish-yellow colour, and is again deposited, on the alcohol cooling, as a brown powder, which is its most characteristic property. It is soluble in alkaline liquids with a dirty brownish-red colour, and is reprecipitated by acids in brown flocks. If it be mixed with alizarine, then its solutions in alkalies have a reddish-purple colour. The ammoniacal solution loses its ammonia on evaporation, and leaves the substance behind as a brown transparent pellicle. The ammoniacal solution gives precipitates with the chlorides of barium and calcium. The alcoholic solution gives dark brown precipitates with the acetates of lead and copper, as I mentioned before. When it is free from alizarine, it does not communicate any colour to mordanted cloth, and is therefore no colouring matter in the usual sense.

In the opinion of most chemists who have examined madder, this root contains two distinct colouring matters, viz. alizarine and another, to which the names of *purpurine*, *oxylizaric acid* and *madder-purple* have been applied by different chemists. This opinion has been advocated with considerable ability by MM. Wolff and Strecker. I have however reason to suppose that purpurine is in fact no distinct substance, but a mixture of alizarine and verantine. The latter substance accompanies almost all the products which are obtained from madder, and it is this body which renders them so difficult to purify. It adheres so pertinaciously to alizarine, as to induce the belief that the two actually form a chemical compound. The mixtures of the two vary in appearance from that of dark red crystals to that of a red crystalline powder. In these mixtures the verantine may easily be detected by dissolving in alcohol and adding acetate of copper, which precipitates the verantine, as before described. It also accompanies rubianine and renders it difficult to crystallize, as I mentioned above, and I have never been able to obtain rubiretine without some trace of it. As a characteristic of purpurine is mentioned its property of giving a cherry-red solution with alkalies, having none of the violet appearance belonging to alkaline solutions of alizarine; and also its forming, when treated with boiling alum-liquor, a red opalescent solution, from which it separates again in orange-coloured flocks on the solution cooling. Now by adding to a solution of alizarine in caustic alkali a little verantine, the beautiful violet colour of the solution may be instantly changed to reddish-purple; and by dissolving in it still more of that substance the colour may be rendered cherry-red, these colours being evidently mixtures of the violet due to alizarine and the brownish-red produced by verantine. Pure alizarine is not more soluble in boiling alum-liquor than in water, as has been repeatedly shown; it only communicates to the liquor a yellow colour, and crystallizes out again on the liquid cooling. Verantine is still less soluble in alum-liquor. If this substance be dissolved in caustic alkali and be then precipitated with a solution of alum, the precipitate does not dissolve in the least degree, however much alum be added; it only communicates a slight yellow tinge to the liquid. If, however, a mixture of alizarine and verantine be dissolved in caustic alkali and they be then precipitated together by means of a solution of alum added in excess, then on boiling the precipitate with the liquid, a bright red solution is obtained, and on filtering and allowing to cool, orange-coloured flocks are deposited, while the liquid still remains red, but gives a yellow precipitate on the addition of acid. By treating the residue with additional quantities of alum-liquor more is dissolved with the same colour, and this continues until either the alizarine or the verantine, whichever of the two was present in the smallest quantity, is removed. From this experiment I am inclined to conclude that alizarine and verantine are capable of forming a double compound with alumina soluble in boiling water, and that a mixture of the two in the proportion in which they exist in this compound, constitutes what has been called purpurine. At all events, it follows that alum is not adapted as a means of separating the substances derived from madder. The fact of rubianine also dissolving in boiling alum-liquor and crystallizing out again on cooling, is an additional objection to its use.

The difficulty of obtaining pure verantine in sufficient quantity for the purposes of analysis, has prevented me from determining its composition with the requisite accuracy. I have however obtained approximations sufficiently near to remove almost all doubts on the question.

I. 0·3280 grm. verantine, dried at 100° C. and burnt with chromate of lead, gave 0·7865 carbonic acid and 0·1215 water.

II. 0·3220 grm. gave 0·7740 carbonic acid and 0·1205 water.

III. 0·2890 grm. gave 0·6995 carbonic acid and 0·1040 water.

IV. 0·1255 grm. gave 0·3010 carbonic acid.

These numbers agree best with the following composition:—

	Eqs.		Calculated.	I.	II.	III.	IV.
Carbon	14	84	65·11	65·39	65·55	66·01	65·41
Hydrogen . . .	5	5	3·87	4·11	4·15	3·99	
Oxygen	5	40	31·02	30·50	30·30	30·00	
		129	100·00	100·00	100·00	100·00	

The composition here given approaches that of the oxylizaric acid of Debus, who obtained in analysing that substance as a mean of his experiments in 100 parts,—

Carbon	66·40
Hydrogen	3·82
Oxygen	29·78

The baryta compound, prepared by precipitating the ammoniacal solution with chloride of barium, gave on analysis the following results:—

0·2605 grm., dried at 100° C. and burnt with chromate of lead, gave 0·4640 carbonic acid and 0·0740 water.

0·4055 grm. gave 0·1835 sulphate of baryta.

In 100 parts:—

Carbon	48·57
Hydrogen	3·15
Oxygen	18·60
Baryta	29·69

The formula $C_{42} H_{13} O_{13} + 2BaO = 2(C_{14} H_4 O_4 + BaO) + C_{14} H_5 O_5$ requires in 100 parts—

Carbon	48·27
Hydrogen	2·49
Oxygen	19·93
Baryta	29·31

The compound with oxide of copper gave the following results:—

0·3680 grm., dried at 100° C. and burnt with chromate of lead, gave 0·7050 carbonic acid and 0·1030 water.

0·4710 grm. gave 0·1200 oxide of copper.

These numbers correspond very nearly to the following composition:—

	Eqs.		Calculated.	Found.
Carbon	14	84	52·50	52·24
Hydrogen	4	4	2·50	3·10
Oxygen	4	32	20·00	19·19
Oxide of copper	1	40	25·00	25·47
		160	100·00	100·00

Another specimen, prepared in exactly the same manner and having the same appearance, gave a different composition.

0·4375 grm. gave 0·8910 carbonic acid and 0·1345 water.

0·5530 grm. gave 0·1080 oxide of copper.

This gives the following composition:—

	Eqs.		Calculated.	Found.
Carbon	56	336	55·17	55·54
Hydrogen.	17	17	2·79	3·41
Oxygen	17	136	22·34	21·53
Oxide of copper	3	120	19·70	19·52
		609	100·00	100·00

The formula of this compound must be expressed in the following manner:

$$3(C_{14} H_4 O_4 + CuO) + C_{14} H_5 O_5.$$

These analyses show that verantine, like many substances, the acid character of which is not well-marked, combines with bases in various and complicated proportions.

It appears therefore that verantine differs from alizarine by containing 1 equiv. more of oxygen. According to Debus, the same relation exists between alizarine and his oxylizaric acid. He gives for alizarine the formula $C_{30}H_{10}O_9$, and for oxylizaric acid $C_{15}H_5O_5$, so that 2 quivs. of the latter contain 1 equiv. more oxygen than 1 equiv. of the former. If my view of the composition of these substances be the correct one, the relation subsisting between the two is still more simple. Nevertheless I have some hesitation in asserting that verantine is to be considered as a higher oxide of the same radical as alizarine, or in supposing that it may be formed by oxidation from the latter. Its formation is due, as I shall presently show, not to any process of oxidation, but rather to the splitting up of an atom of rubian into two bodies.

Rubiretine.—This substance is identical with that which I formerly called the alpha-resin of madder, from which it does not differ in properties. It is obtained as a dark brown, opake, resinous mass, brittle when cold, but becoming soft and almost melting in boiling water. On being heated to a higher degree, it melts completely without being decomposed. It is generally found to be mixed with a small quantity of verantine, from which it may be separated by solution in cold alcohol, which leaves the greatest part of the verantine behind; I have however found it impossible to remove the last traces of that substance. It is almost insoluble in boiling water. Its solution in alcohol is dark yellow. It dissolves in concentrated sulphuric acid with a yellowish-brown colour, and is decomposed on boiling the solution with blackening and disengagement of sulphurous acid. Boiling nitric acid changes it into a yellow substance, which no longer softens at the temperature of boiling water, and is very little soluble in alcohol. It dissolves in alkaline liquids with a brownish-red colour, and is reprecipitated by acids in brown flocks, which on boiling the liquid cohere into dark-brown semifluid masses. When heated in a glass tube, it usually gives a small quantity of sublimed alizarine mixed with a brown oil. It is not capable of dyeing when quite free from alizarine. Its analysis yielded the following results:—

I. 0·5300 grm. from the decomposition of rubian, dried at 100° C. and burnt with chromate of lead, gave 1·3190 carbonic acid and 0·2405 water.

II. 0·3785 grm. of the same preparation as the last, heated to the melting-point, gave 0·9465 carbonic acid and 0·1730 water.

III. 0·4815 grm. obtained directly from madder, dried at 100° C., gave 1·2130 carbonic acid and 0·2335 water.

IV. 0·4290 grm. of the same preparation as the last, heated to the melting-point, gave 1·0735 carbonic acid and 0·2050 water.

V. 0·3120 grm. of another preparation obtained directly from madder, gave 0·7855 carbonic acid and 0·1460 water.

VI. 0·2350 grm. of the same preparation as the last, gave 0·5865 carbonic acid and 0·1065 water.

In 100 parts it therefore contains—

	I.	II.	III.	IV.	V.	VI.
Carbon	67·87	68·19	68·70	68·24	68·66	68·06
Hydrogen . . .	5·04	5·07	5·38	5·30	5·20	5·03
Oxygen . . .	27·09	26·74	25·92	26·46	26·14	26·91

I endeavoured in vain to determine the atomic weight of this substance. Neither the lead nor the baryta compound gave results which harmonized either with one another or with the analyses of the substance itself. There is however only one formula which is in accordance with the analyses, and at the same time satisfactorily explains its formation. This formula is $C_{14}H_6O_4$, which requires in 100 parts—

Carbon	68·85
Hydrogen	4·91
Oxygen	26·24

It may be remarked that this is also the composition of benzoic acid; and even if the formula of rubiretine should not be exactly that given above, but perhaps the double or triple of it, it still remains remarkable that two such very different substances should have the same percentary composition.

The formation of rubiretine from rubian can only be explained in connection with that of verantine. If 2 equivs. of verantine, 2 equivs. of rubiretine and 12 equivs. of water be added together, the sum will be equal to 1 equiv. of rubian, as follows:—

$$\begin{array}{lcl} \text{2 equivs. of Verantine} & = & C_{28}H_{10}O_{10} \\ \text{2 equivs. of Rubiretine} & = & C_{28}H_{12}O_{8} \\ \text{12 equivs. of Water} & = & \quad H_{12}O_{12} \\ \hline \text{1 equiv. of Rubian} & = & C_{56}H_{34}O_{30} \end{array}$$

If this be the correct representation, it follows that verantine and rubiretine stand in an intimate relation to one another, that the formation of one always indicates that of the other. In confirmation of this view, I may state that I have never seen the formation of one of these substances taking place without it being possible to detect the presence of the other.

Rubianine.—This substance, as I mentioned before, has not hitherto been observed among the bodies derived from madder. It greatly resembles rubiacine in its appearance and many of its properties; it may however easily be distinguished by several characteristics, and above all by its composition. It is obtained from a solution in boiling alcohol in the form of bright lemon-yellow, silky needles, which, when dry, form an interwoven mass. It is soluble in boiling water, more so in fact than any of the products of decomposition hitherto mentioned. It crystallizes out again on the solution cooling in yellow silky needles. It is less soluble in alcohol than the preceding substances. Its colour is lighter than that of rubiacine. When heated on platinum-foil it melts to a brown liquid, then burns, leaving a carbonaceous residue, which on further heating disappears entirely. When heated in a glass tube it gives a small quantity of a yellow crystalline sublimate, but not by far so large a quantity as is obtained under the same circumstances from rubiacine, which, when carefully heated, may be almost entirely volatilized. It is soluble in concentrated sulphuric acid with a yellow colour; the solution on boiling becomes black and gives off sulphurous acid. A solution of rubiacine in concentrated sulphuric acid, remains quite unchanged on boiling. It is not affected either by dilute or concentrated nitric acid, even on boiling; it merely dissolves in them, and crystallizes out again on the acid cooling, just as from boiling water. When treated in the cold with a solution of carbonate of potash or soda, or liquid ammonia, it does not dissolve, nor is its colour at all changed. When the liquid is boiled, it dissolves however with a blood-red colour. Nevertheless it cannot be said to combine with the alkali, but merely to be dissolved by it; for on allowing these solutions to stand for some time, a yellow crystalline mass again separates, which is nothing but the substance itself. The ammoniacal solution gives red precipitates with the chlorides of barium and calcium. The alcoholic solution gives no precipitate with sugar of lead, whereas a solution of rubiacine gives a dark red precipitate with sugar of lead. It dissolves in a concentrated solution of perchloride of iron with a dark brown colour, but is not thereby converted into rubiacic acid. It communicates to mordanted cloth only a slight tinge of colour, similar to that produced by rubiacine.

Its analysis gave the following results:—

I. 0·3520 grm. substance, dried at 100° C. and burnt with chromate of lead, gave 0·7400 carbonic acid and 0·1750 water.

II. 0·3805 grm. of the same preparation gave 0·7990 carbonic acid and 0·1890 water.

III. 0·3965 grm. of another preparation gave 0·8330 carbonic acid and 0·1890 water.

IV. 0·2480 grm. of the same preparation as the last, recrystallized from alcohol, gave 0·5290 carbonic acid and 0·1280 water.

V. 0·3735 grm. of a third preparation gave 0·7925 carbonic acid and 0·1785 water.

VI. 0·3995 grm. of the same preparation gave 0·8450 carbonic acid and 0·1855 water.

These numbers correspond in 100 parts to—

	I.	II.	III.	IV.	V.	VI.
Carbon	57·33	57·26	57·29	58·17	57·86	57·68
Hydrogen . . .	5·52	5·51	5·29	5·73	5·31	5·15
Oxygen	37·15	37·23	37·42	36·10	36·83	37·17

I have as yet been unsuccessful in my attempts to determine the atomic weight of rubianine. The little affinity which it has for bases is proved by the fact above mentioned, of its crystallizing unchanged out of its alkaline solutions. The baryta compound, which is obtained by adding chloride of barium to its ammoniacal solution, is easily decomposed when it comes to be washed with pure water, the baryta being dissolved by the water, a yellow residue of rubianine being left at last. It is not capable of separating oxide of lead from acetic acid. In fact it nearly approaches the character of a perfectly neutral body, a circumstance which might be *à priori* foreseen from its containing more carbon and less oxygen than rubian itself, the properties of which are not far removed from those of an indifferent substance.

There are three formulæ which all of them give for 100 parts, numbers not widely differing from those found by experiment, viz. $C_{28} H_{17} O_{13}$, $C_{32} H_{19} O_{15}$ and $C_{44} H_{24} O_{20}$. These formulæ require for 100 parts of substance the following amount of constituents:—

	$C_{28} H_{17} O_{13}$.	$C_{32} H_{19} O_{15}$.	$C_{44} H_{24} O_{20}$.
Carbon	58·13	58·00	57·99
Hydrogen	5·88	5·74	5·47
Oxygen	35·99	36·26	36·54

It will be seen that the last formula is that with which the analyses agree best.

If the first formula be the true one, then the formation of this substance from rubian is easily explained. It would then differ by 5 equivs. of water from 2 equivs. of rubiretine; and 1 equiv. of rubianine, 2 equivs. of verantine and 7 equivs. of water added together would be equal to 1 equiv. of rubian, as seen by the following equation:

$$C_{28} H_{17} O_{13}+2(C_{14} H_5 O_5)+7HO=C_{56} H_{34} O_{30}.$$

I shall presently show, however, that there is more probability in favour of one of the two latter formulæ.

Sugar.—That the substance obtained from the acid liquid after the complete decomposition of rubian is a species of sugar, will, I think, be apparent from an enumeration of its properties. It is always obtained in the form of a transparent yellow syrup, which neither crystallizes, however long its solution may be left to stand, nor becomes dry, unless heated to 100° C. Its taste is sweetish, accompanied by a bitter aftertaste, like that of burnt sugar. When heated for some time at 100° C. it loses a portion of its water, but remains soft and viscid. On allowing it however to cool, it becomes brittle and capable of pulverization. After a few moments' exposure to the air it again begins to attract moisture, which it does as rapidly as chloride of calcium, and is soon reconverted into syrup. This is a character which it has, in common with ordinary syrup, obtained by boiling a solution of cane-sugar in water. It is soluble in alcohol. It is not affected by dilute sulphuric acid, even on boiling; but on evaporating a solution to which sulphuric acid has been added, it is decomposed in proportion as the acid becomes concentrated, and is changed into a black powder like humus. Concentrated sulphuric acid destroys it immediately with disengagement of sulphurous acid. It is destroyed by nitric acid. By operating on a moderately large quantity of it, I was enabled to ascertain that the sole product of the action of nitric acid is oxalic acid. It is not precipitated from its watery solution by any metallic or other salt, not even by basic acetate of lead. On the addition of caustic potash or soda to its solution and boiling, the solution immediately becomes brown, and a brown powder falls, just as in the case of grape-sugar. It is capable of fermentation. The watery solution when mixed with yeast soon begins to ferment, though the process is not so lively as in the case of an equal quantity of common sugar; and by distilling the liquid and boiling the distillate with dry carbonate of soda, alcohol may be obtained.

The analysis was attended with some difficulty on account of the great affinity which it has for water. By heating it however for some time at 100° C., then allowing to cool and pulverizing while in its brittle state as quickly as possible, it was obtained in a condition fit for analysis. Even then however the state of hydration was not uniform, so that the analyses differed considerably from one another. The following results were obtained:—

I. 0·4765 grm., burnt with chromate of lead, gave 0·6860 carbonic acid and 0·2905 water.

II. 0·3050 grm. gave 0·4450 carbonic acid and 0·1815 water.

III. 0·3820 grm. gave 0·5650 carbonic acid and 0·2205 water.

These numbers give in 100 parts—

	I.	II.	III.
Carbon	39·26	39·79	40·33
Hydrogen . . .	6·77	6·61	6·41
Oxygen	53·97	53·60	53·26

As this substance does not combine with bases, its atomic weight could not be determined by direct experiment. There are, however, two formulæ, both of which agree with the analyses and explain its formation, viz. $C_{14}\,H_{14}\,O_{14}$ and $C_{12}\,H_{12}\,O_{12}$. Both of these formulæ require in 100 parts—

Carbon	40·00
Hydrogen	6·66
Oxygen	53·34

If the formula $C_{14}\,H_{14}\,O_{14}$ be the true one, then its formation from rubian admits of an easy explanation. It would then differ from verantine by 9 equivs. of water; and by adding together 2 equivs. of it and 2 equivs. of rubiretine, the sum would be equal to 1 equiv. of rubian plus 6 equivs. of water, as the following equation shows:—

$$\left.\begin{array}{ll}\text{2 equivs. of Sugar . .} & =C_{28}\,H_{28}\,O_{28}\\ \text{2 equivs. of Rubiretine} & =C_{28}\,H_{12}\,O_{8}\end{array}\right\}=\left\{\begin{array}{l}C_{56}\,H_{34}\,O_{30}=\text{1 equiv. of Rubian.}\\ \quad\;\; H_{6}\,O_{6}=\text{6 equivs. of Water.}\end{array}\right.$$

$$\overline{C_{56}\,H_{40}\,O_{36}}\qquad\overline{C_{56}\,H_{40}\,O_{36}}$$

If the formula of rubianine be $C_{28}\,H_{17}\,O_{13}$, it may replace rubiretine in the above equation; 11 equivs. of water instead of 6 being added to the rubian, as follows,—

$$\left.\begin{array}{ll}\text{2 equivs. of Sugar . .} & =C_{28}\,H_{28}\,O_{28}\\ \text{1 equiv. of Rubianine .} & =C_{28}\,H_{17}\,O_{13}\end{array}\right\}=\left\{\begin{array}{l}C_{56}\,H_{34}\,O_{30}=\text{1 equiv. of Rubian.}\\ \quad\;\; H_{11}\,O_{11}=\text{11 equivs. of Water.}\end{array}\right.$$

$$\overline{C_{56}\,H_{45}\,O_{41}}\qquad\overline{C_{56}\,H_{45}\,O_{41}}$$

To this view however it may be objected that all the species of sugar capable of fermentation with which we are acquainted contain 12 equivs. of carbon. Indeed it is difficult to conceive how a body of the formula $C_{14}H_{14}O_{14}$ can be decomposed into alcohol and carbonic acid. It is therefore far more probable that the formula of this substance is $C_{12}H_{12}O_{12}$, which is also that of grape-sugar when dried at 100° C. In fact, were it capable of being crystallized, it would no doubt be considered as identical with grape-sugar. If this be granted, then it follows that the formula of rubianine must be either $C_{32}H_{19}O_{15}$ or $C_{44}H_{24}O_{20}$, as will be seen by the following equations:—

$$\left.\begin{array}{ll}\text{2 equivs. of Sugar} \;\;.\;\;. & =C_{24}H_{24}O_{24} \\ \text{1 equiv. of Rubianine} \;\;. & =C_{32}H_{19}O_{15}\end{array}\right\}=\left\{\begin{array}{l}C_{56}H_{34}O_{30}=\text{1 equiv. of Rubian.} \\ \quad H_{9}O_{9}=\text{9 equivs. of Water.}\end{array}\right.$$

$$C_{56}H_{43}O_{39} \qquad C_{56}H_{43}O_{39}$$

or

$$\left.\begin{array}{ll}\text{1 equiv. of Sugar} \;\;.\;\;. & =C_{12}H_{12}O_{12} \\ \text{1 equiv. of Rubianine} \;\;. & =C_{44}H_{24}O_{20}\end{array}\right\}=\left\{\begin{array}{l}C_{56}H_{34}O_{30}=\text{1 equiv. of Rubian.} \\ \quad H_{2}O_{2}=\text{2 equivs. of Water.}\end{array}\right.$$

$$C_{56}H_{36}O_{32} \qquad C_{56}H_{36}O_{32}$$

The formula $C_{44}H_{24}O_{20}$ seems to me the more probable of the two. It agrees best with the results of analysis, and the high atomic weight of rubianine which follows from it explains the very neutral character of that substance. Hence it appears that rubianine stands in the same relation to the sugar as rubiretine does to verantine. When added together they contain the elements of rubian plus the elements of water, while rubiretine and verantine added together contain the elements of rubian minus the elements of water.

On the whole, it appears that the action of acids on rubian is not of so complicated a nature as might at first sight be supposed. The number of substances produced by this action is five. Nevertheless it does not follow that these five substances are all formed together, or in other words, that one atom of rubian by its decomposition gives rise to all five at the same time. From the composition of these substances, as compared with that of rubian, it follows that the latter by the action of acids undergoes decomposition in three different directions, or more correctly speaking, that the decomposition affects three separate atoms of rubian. One of these atoms loses 14 atoms of water, and is converted into alizarine. The second loses 12 atoms of water, and then splits up into verantine and rubiretine. The third takes up the elements of water, and then splits up into rubianine and sugar. What the circumstances are under which either one or the other of these three processes takes place I am unable to say. That the loss of a greater or smaller proportion of water or the addition, on the contrary, of the elements of water to those of rubian, are the immediate efficient causes of one or the other of the three processes taking place is very probable; but what again determines the elimination of more or less water from rubian, or, on the other hand, its combination with more water, remains uncertain. It is not unlikely however that the degree of temperature at which the decomposition is effected may have something to do with it. It is probable that the lower the temperature at which the acid acts on the rubian, the more rubianine and sugar are formed, and that at a higher temperature more alizarine, verantine and rubiretine are produced. In all experiments hitherto mentioned I have always obtained all five products of decomposition, though by no means in equal proportions, the alizarine being formed in the smallest quantity, the amount of rubiretine and verantine being somewhat greater, and the rubianine and sugar being produced in the largest quantity. In the course of this paper I shall have occasion to mention circumstances in which a still greater preponderance takes place in the amount of several of these substances formed over that of the others. Whether it would be possible to confine the decomposition of rubian entirely to one of these processes, or whether all three are essential, is a question of the highest importance, not so much in a theoretical, as a practical point of view. That beautiful substance, alizarine, is the only one of these products which is capable of yielding dyes. It is this body which in my opinion gives rise to all the beautiful colours for the production of which madder is employed. The others are not only useless, they are positively injurious, as I have shown on a former occasion. Though experimentally alizarine is formed in the smallest proportion, it is nevertheless theoretically possible to convert rubian entirely into alizarine, without the least quantity of the other substances being produced. From this point of view the other substances may be considered as formed at the expense of alizarine. In fact, by adding together 1 equiv. of verantine and 1 equiv. of rubiretine, and subtracting 1 equiv. of water, we obtain the elements of 2 equivs. of alizarine, for

$$C_{14}H_5O_5+C_{14}H_6O_4=2(C_{14}H_5O_4)+HO.$$

Also by adding together 1 equiv. of rubianine and 1 equiv. of sugar, and subtracting 16 equivs. of water, we obtain the elements of 4 equivs. of alizarine, for

$$C_{44}H_{24}O_{20}+C_{12}H_{12}O_{12}=4(C_{14}H_5O_4)+16HO.$$

If any chemist should succeed in changing rubian entirely into alizarine, an undertaking in which there is no occasion to despair of success, he would be the means of giving a great stimulus to many branches of manufacture and adding a large sum to the national wealth.

XIX. *On the Solution of Linear Differential Equations.* *By the Rev.* B. Bronwin. *Communicated by* Samuel Hunter Christie, *Esq., Sec. R.S. &c.*

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If we consider the very different forms which the solutions of Differential Equations differing very little from each other frequently take, and the very different processes often required in each particular case to obtain the solution, we shall be led to conclude that the discovery of any universal or general method of solving them must be a hopeless case. We cannot therefore regard particular methods, especially when applicable to a large number of cases, as useless speculations. The present paper contains the solution of several classes of these equations effected by means of general theorems in the Calculus of Operations adapted to each particular class. For explanation of the symbols employed, let it be observed that D is put for $\frac{d}{dx}$, and that φ, λ, Ψ, and X denote any functions of x, the independent variable, and are the same as $\varphi(x)$, $\lambda(x)$, &c.; and in like manner $\varphi(\mathrm{D})$, $\lambda(\mathrm{D})$, &c. will be used to denote the same functions of D.

I. FIRST GENERAL THEOREM IN THE CALCULUS OF OPERATIONS.

Let $\tau=\varepsilon^{\int\frac{dx}{\varphi}}$, $\varpi=\varphi\mathrm{D}+\lambda$. We easily verify

$$(\varpi+k)u=\tau^{-k}\varpi\tau^{k}u$$

by substituting for τ and ϖ, and then performing the operations indicated in the result. Change u into $(\varpi+k)u$ in the first member, and into its equal $\tau^{-k}\varpi\tau^{k}u$ in the second, and there results

$$(\varpi+k)^{2}u=\tau^{-k}\varpi^{2}\tau^{k}u.$$

A repetition of this process will produce

$$(\varpi+k)^{3}u=\tau^{-k}\varpi^{3}\tau^{k}u.$$

In like manner similar equations will be found for higher powers. But the first gives

$$u=(\varpi+k)^{-1}\tau^{-k}\varpi\tau^{k}u.$$

Change u into $\tau^{-k}\varpi^{-1}\tau^{k}u$, and we have

$$\tau^{-k}\varpi^{-1}\tau^{k}u=(\varpi+k)^{-1}u,$$

or transposing,

$$(\varpi+k)^{-1}u=\tau^{-k}\varpi^{-1}\tau^{k}u.$$

Now change u into $(\varpi+k)^{-1}u$ in the first member, and into its equal $\tau^{-k}\varpi^{-1}\tau^{k}u$ in the second, and the result is

$$(\varpi+k)^{-2}u=\tau^{-k}\varpi^{-2}\tau^{k}u\,;$$

and so on. Therefore if $f(\varpi)$ be any function developable in integer powers of ϖ, positive or negative, we shall have

$$f(\varpi+k)u=\tau^{-k}f(\varpi)\tau^{k}u,$$

or

$$\tau^{k}f(\varpi+k)u=f(\varpi)\tau^{k}u. \quad \ldots\ldots\ldots\ldots \quad (a.)$$

The assumption $\tau=\varepsilon^{\int\frac{dx}{\varphi}}$ gives $\frac{1}{\varphi}=\frac{\tau'}{\tau}$, and we may regard either τ or φ as the quantity given from which the other is to be found.

Application of the preceding Theorem to the Solution or Reduction of an extensive class of Linear Differential Equations.

To abridge we shall put

$$(\varpi+a)(\varpi+a+k)\ldots(\varpi+a+nk)=\mathrm{P}\begin{Bmatrix}a+nk\\a\end{Bmatrix},$$

$$(\varpi+a)^{-1}(\varpi+a+k)^{-1}\ldots\ldots(\varpi+a+nk)^{-1}=\mathrm{P}\begin{Bmatrix}a+nk\\a\end{Bmatrix}^{-1};$$

and similarly in other cases. But it is to be observed that we may resolve the last into

$$\frac{\mathrm{A}}{\varpi+a}+\frac{\mathrm{A}_1}{\varpi+a+k}+\ldots\ldots+\frac{\mathrm{A}_n}{\varpi+a+nk},$$

which in practice may be more convenient. The operations implied by the reciprocal factors may be readily performed by a well-known theorem due to Mr. Boole.

Thus $$(\varpi+m)^{-1}\mathrm{X}=(\varphi\mathrm{D}+\lambda+m)^{-1}\mathrm{X}=\left(\mathrm{D}+\frac{\lambda+m}{\varphi}\right)^{-1}\varphi^{-1}\mathrm{X}$$

$$=\varepsilon^{-\int\frac{\lambda+m}{\varphi}dx}\mathrm{D}^{-1}\varepsilon^{\int\frac{\lambda+m}{\varphi}dx}\varphi^{-1}\mathrm{X}.$$

Now let

$$f(\varpi)\varpi u+pf_{\prime}(\varpi)(\varpi+nk)\tau^{k}u=\mathrm{X}, \quad \ldots\ldots\ldots\ldots \quad (1.)$$

where $f(\varpi)$ and $f_{\prime}(\varpi)$ are any rational functions of ϖ, and k may be either positive or negative. To reduce this, assume

$$u=(\varpi+k)(\varpi+2k)\ldots\ldots(\varpi+nk)v.$$

Then by (*a.*)

$$\tau^{k}u=\tau^{k}(\varpi+k)\ldots.(\varpi+nk)v=\varpi(\varpi+k)\ldots.(\varpi+(n-1)k)\tau^{k}v.$$

Substituting these values in (1.), and operating on both members of the result with

$$\varpi^{-1}(\varpi+k)^{-1}\ldots.(\varpi+nk)^{-1}=\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1},$$

we find

$$f(\varpi)v+pf_{\prime}(\varpi)\tau^{k}v=\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X}, \quad \ldots\ldots\ldots\ldots \quad (2.)$$

which is one order lower than the proposed. All equations therefore of the second order included in (1.) may be considered as integrated by this process.

Another form, distinct from the above, is

$$f(\varpi)(\varpi+nk)u+pf_{\prime}(\varpi)\varpi\tau^{k}u=\mathrm{X}. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3.)$$

To reduce this we must assume

$$u=(\varpi+k)^{-1}(\varpi+2k)^{-1}\ldots.(\varpi+nk)^{-1}v.$$

Then by (*a.*) we have

$$\tau^{k}u=\varpi^{-1}(\varpi+k)^{-1}\ldots.(\varpi+(n-1)k)^{-1}\tau^{k}v.$$

Substituting these values and operating with $(\varpi+k)\ldots(\varpi+(n-1)k)$ on both members of the result, we have

$$f(\varpi)v+pf_{\prime}(\varpi)\tau^{k}v=\mathrm{P}\begin{Bmatrix}(n-1)k\\ k\end{Bmatrix}\mathrm{X}. \quad . \; . \; . \; . \; . \; . \; . \; . \quad (4.)$$

The observations made with reference to the former example might be repeated here. I shall add, that as k may be both positive and negative, these two examples include every variety of case of this form of equation.

Before I proceed to notice particular examples, it may be as well to give a few more general ones, and thus to point out the whole series of them which are susceptible of reduction by this method.

Let $$f(\varpi)\varpi(\varpi+k)u+pf_{\prime}(\varpi)(\varpi+nk)\tau^{2k}u=\mathrm{X}. \quad . \; . \; . \; . \; . \; . \; . \quad (5.)$$

Make $$u=(\varpi+2k)(\varpi+3k)\ldots..(\varpi+(n+1)k)v,$$

the common difference of the factors being k, as before, which here also may be both positive and negative. This will give

$$\tau^{2k}u=\varpi(\varpi+k)\ldots..(\varpi+(n-1)k)\tau^{2k}v,$$

and proceeding exactly as before, we shall arrive at the reduced equation,

$$f(\varpi)(\varpi+(n+1)k)v+pf_{\prime}(\varpi)\tau^{2k}v=\mathrm{P}\begin{Bmatrix}nk\\ 0\end{Bmatrix}^{-1}\mathrm{X}. \quad . \; . \; . \; . \; . \; . \quad (6.)$$

Again, suppose

$$f(\varpi)(\varpi+nk)(\varpi+nk+k)u+pf_{\prime}(\varpi)\varpi\tau^{2k}u=\mathrm{X}. \quad . \; . \; . \; . \; . \; . \quad (7.)$$

The assumption

$$u=(\varpi+2k)^{-1}(\varpi+3k)^{-1}\ldots.(\varpi+(n+1)k)^{-1}v$$

leads to

$$f(\varpi)(\varpi+k)v+pf_{\prime}(\varpi)\tau^{2k}v=\mathrm{P}\begin{Bmatrix}(n-1)k\\ k\end{Bmatrix}\mathrm{X}. \quad . \; . \; . \; . \; . \; . \; . \quad (8.)$$

The two last examples, like the former, are reduced an order lower; and when they are of the second order, they may be considered as integrated. In order to enable us to effect their reduction, it is necessary that we should have two operating factors, as $\varpi(\varpi+k)$, in one of the terms, these factors having the difference k. I shall only give two more examples, which will suffice to indicate the series of them before mentioned.

Let
$$f(\varpi)\varpi(\varpi+k)(\varpi+2k)u+pf_{\prime}(\varpi)(\varpi+nk)\tau^{3k}u=\mathrm{X},$$
and
$$f(\varpi)(\varpi+nk)(\varpi+nk+k)(\varpi+nk+2k)u+pf_{\prime}(\varpi)\varpi\tau^{3k}u=\mathrm{X}.$$

The first of these, by making
$$u=(\varpi+3k)(\varpi+4k)\ldots.(\varpi+(n+2)k)v,$$
will reduce to
$$f(\varpi)(\varpi+nk+k)(\varpi+nk+2k)v+p\tau^{3k}v=\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X},$$
and the second, by putting
$$u=(\varpi+3k)^{-1}\ldots.(\varpi+(n+2)k)^{-1}v,$$
reduces to
$$f(\varpi)(\varpi+k)(\varpi+2k)v+p\tau^{3k}v=\mathrm{P}\begin{Bmatrix}(n-1)k\\k\end{Bmatrix}\mathrm{X}.$$

It will be observed that the equations in the two last examples are of the third order at the lowest, and those to which they are reduced of the second; and if we were to continue the series, they would rise an order at every step. But we will here leave them and proceed to give a few particular examples.

In (1.) and (2.) make
$$f(\varpi)=\varpi+a,\ f_{\prime}(\varpi)=1\,;$$
and they become
$$\varpi(\varpi+a)u+p(\varpi+nk)\tau^{k}u=\mathrm{X}\ \ldots\ldots\ldots\ldots \quad (9.)$$
$$(\varpi+a)v+p\tau^{k}v=\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X}.$$
The last gives
$$v=(\varpi+a+p\tau^{k})^{-1}\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X},$$
and therefore
$$u=\mathrm{P}\begin{Bmatrix}nk\\k\end{Bmatrix}(\varpi+a+p\tau^{k})^{-1}\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X}.$$

It is not necessary to reduce the value of u any further, as the mode of doing it has been made sufficiently plain, and moreover it is quite as convenient as it stands. We shall only observe that if, to abridge, we make
$$\frac{\lambda+a+p\tau^{k}}{\varphi}=\Phi,$$
we have
$$(\varpi+a+p\tau^{k})^{-1}=(\mathrm{D}+\Phi)^{-1}\varphi^{-1}=\varepsilon^{-\int\Phi dx}\mathrm{D}^{-1}\varepsilon^{\int\Phi dx}\varphi^{-1}.$$

If we wish to see (9.) under the ordinary form, it is easily reduced, first to
$$\varpi^{2}u+(a+p\tau^{k})\varpi u+(n+1)kp\tau^{k}u=\mathrm{X}\,;$$
and then by substituting for ϖ to
$$\varphi^{2}\mathrm{D}^{2}u+\varphi(\varphi'+2\lambda+a+p\tau^{k})\mathrm{D}u+(\varphi\lambda'+\lambda^{2}+(a+p\tau^{k})\lambda+(n+1)kp\tau^{k})u=\mathrm{X}.$$

If we would deduce particular integrable equations from this, we may assume τ and λ any functions of x at pleasure, and the relation $\frac{1}{\varphi}=\frac{\tau'}{\tau}$ will give φ. It will be observed that the accent upon τ, λ, and ϕ is employed to denote differential coefficients. But as this equation, and many more which may be deduced, contain two arbitrary functions of the independent variable, the number of particular practicable forms is immense. To select examples therefore would be very difficult.

Now make in (1.) and (2.)

$$f(\varpi)=\varpi+a,\quad f_{\prime}(\varpi)=\varpi+b,$$

and we have

$$\varpi(\varpi+a)u+p(\varpi+b)(\varpi+nk)\tau^k u=\mathrm{X}\quad\ldots\ldots\ldots\quad(10.)$$

$$(\varpi+a)v+p(\varpi+b)\tau^k v=\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X},$$

or

$$(\varpi+a)v+p\tau^k(\varpi+b+k)v=\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X},$$

and therefore

$$(1+p\tau^k)\varpi v+(a+(b+k)p\tau^k)v=\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X}.$$

To abridge make

$$\frac{a+(b+k)p\tau^k}{1+p\tau^k}=\Phi,$$

and the last equation becomes

$$(1+p\tau^k)(\varpi+\Phi)v=\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X};$$

whence

$$v=(\varpi+\Phi)^{-1}(1+p\tau^k)^{-1}\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X},\quad u=\mathrm{P}\begin{Bmatrix}nk\\k\end{Bmatrix}(\varpi+\Phi)^{-1}(1+p\tau^k)^{-1}\mathrm{P}\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X}.$$

Similarly, from (3.) and (4.) we derive

$$(\varpi+a)(\varpi+nk)u+p\varpi\tau^k u=\mathrm{X},\quad\ldots\ldots\ldots\quad(11.)$$

where

$$u=\mathrm{P}\begin{Bmatrix}nk\\k\end{Bmatrix}^{-1}(\varpi+a+p\tau^k)^{-1}\mathrm{P}\begin{Bmatrix}(n-1)k\\k\end{Bmatrix}\mathrm{X}.$$

The last equation, reduced to the ordinary form, making $c=a+nk$, becomes

$$\phi^2\mathrm{D}^2u+\phi(\phi'+2\lambda+c+p\tau^k)\mathrm{D}u+(\phi\lambda'+\lambda^2+(c+p\tau^k)\lambda+nak+kp\tau^k)u=\mathrm{X}.$$

From (3.) and (4.) we also deduce

$$(\varpi+a)(\varpi+nk)u+p\varpi(\varpi+b)\tau^k u=\mathrm{X}\quad\ldots\ldots\ldots\quad(12.)$$

$$(\varpi+a)v+p(\varpi+b)\tau^k v=\mathrm{P}\begin{Bmatrix}(n-1)k\\k\end{Bmatrix}\mathrm{X}.$$

From these, exactly as in (10.), we find

$$u=\mathrm{P}\begin{Bmatrix}nk\\k\end{Bmatrix}^{-1}(\varpi+\Phi)^{-1}(1+p\tau^k)^{-1}\mathrm{P}\begin{Bmatrix}(n-1)k\\k\end{Bmatrix}\mathrm{X},$$

where Φ has the same value as in (10.).

The examples (10.) and (12.), if reduced to the ordinary form, would be very different from those which have been so reduced, and they would be considerably more complex. And we may observe that if the functions $f(\varpi), f_{/}(\varpi)$ in (1.), (3.), &c. have suitable factors, the reduced equations (2.), (4.), &c. may be still further reduced by the same means, the proposed equations in this case being of an order above the second.

From (5.) and (6.), making $f(\varpi)=f_{/}(\varpi)=1$, we have

$$\varpi(\varpi+k)u+p(\varpi+nk)\tau^{2k}u=\mathrm{X} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13.)$$

and

$$(\varpi+(n+1)k)v+p\tau^{2k}v=\mathrm{P}\left\{\begin{matrix} nk \\ 0 \end{matrix}\right\}^{-1}\mathrm{X};$$

whence

$$v=\{\varpi+(n+1)k+p\tau^{2k}\}^{-1}\mathrm{P}\left\{\begin{matrix} nk \\ 0 \end{matrix}\right\}^{-1}\mathrm{X},$$

$$u=\mathrm{P}\left\{\begin{matrix} (n+1)k \\ 2k \end{matrix}\right\}\{\varpi+(n+1)k+p\tau^{2k}\}^{-1}\mathrm{P}\left\{\begin{matrix} nk \\ 0 \end{matrix}\right\}^{-1}\mathrm{X}.$$

Similarly, from (7.) and (8.) we find

$$(\varpi+nk)(\varpi+nk+k)u+p\varpi\tau^{2k}u=\mathrm{X}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14.)$$

$$v=\{\varpi+k+p\tau^{2k}\}^{-1}\mathrm{P}\left\{\begin{matrix} (n-1)k \\ k \end{matrix}\right\}\mathrm{X},$$

$$u=\mathrm{P}\left\{\begin{matrix} (n+1)k \\ 2k \end{matrix}\right\}^{-1}\{\varpi+k+p\tau^{2k}\}^{-1}\mathrm{P}\left\{\begin{matrix} (n-1)k \\ k \end{matrix}\right\}\mathrm{X}.$$

The two last examples, reduced to the ordinary form, are

$$\varphi^2\mathrm{D}^2u+\varphi(\varphi'+2\lambda+k+p\tau^{2k})\mathrm{D}u+(\varphi\lambda'+\lambda^2+\lambda(k+p\tau^{2k})+(n+2)kp\tau^{2k})u=\mathrm{X},$$

and

$$\varphi^2\mathrm{D}^2u+\varphi(\varphi'+2\lambda+(2n+1)k+p\tau^{2k})\mathrm{D}u+(\varphi\lambda'+\lambda^2+(2n+1)k\lambda+(2k+\lambda)p\tau^{2k}+n(n+1)k^2)u=$$

respectively.

I shall only give two other examples, derived from the same source with the two preceding.

$$\varpi(\varpi+k)u+p(\varpi+a)(\varpi+nk)\tau^{2k}u=\mathrm{X},$$

$$u=\mathrm{P}\left\{\begin{matrix} (n+1)k \\ 2k \end{matrix}\right\}(\varpi+\Psi)^{-1}(1+p\tau^{2k})^{-1}\mathrm{P}\left\{\begin{matrix} nk \\ 0 \end{matrix}\right\}^{-1}\mathrm{X}$$

$$(\varpi+nk)(\varpi+nk+k)u+p\varpi(\varpi+a)\tau^{2k}u=\mathrm{X},$$

$$u=\mathrm{P}\left\{\begin{matrix} (n+1)k \\ 2k \end{matrix}\right\}^{-1}(\varpi+\Phi)^{-1}(1+p\tau^{2k})^{-1}\mathrm{P}\left\{\begin{matrix} (n-1)k \\ k \end{matrix}\right\}\mathrm{X};$$

where

$$\Psi=\frac{(n+1)k+(a+2k)p\tau^{2k}}{1+p\tau^{2k}}, \quad \Phi=\frac{k+(a+2k)p\tau^{2k}}{1+p\tau^{2k}}.$$

II. SECOND GENERAL THEOREM IN THE CALCULUS OF OPERATIONS.

Make $\mathrm{D}=\mathrm{D}_1+\mathrm{D}_2$, D_1 operating upon u only and D_2 upon x only. Then by TAYLOR's theorem

$$f(\mathrm{D})=f(\mathrm{D}_1+\mathrm{D}_2)=f(\mathrm{D}_1)+\mathrm{D}_2f'(\mathrm{D}_1)+\tfrac{1}{2}\mathrm{D}_2^2f''(\mathrm{D}_1)+\dots$$

This formula will be of frequent use in the subsequent part of this paper. By it

$$\varepsilon^{kf(\mathrm{D})}=\varepsilon^{kf(\mathrm{D}_1)+k\mathrm{D}_2f'(\mathrm{D}_1)+\dots}=\varepsilon^{kf(\mathrm{D}_1)}\varepsilon^{k\mathrm{D}_2f'(\mathrm{D}_1)+}=\{1+k\mathrm{D}_2f'(\mathrm{D}_1)+\}\varepsilon^{kf(\mathrm{D}_1)}.$$

Operate with both members of this upon $\{\varphi(\mathrm{D})x+\lambda(\mathrm{D})\}u$, and we have

$$\varepsilon^{kf(\mathrm{D})}\{\varphi(\mathrm{D})x+\lambda(\mathrm{D})\}u=\{\varphi(\mathrm{D})x+\lambda(\mathrm{D})+k\varphi(\mathrm{D})f'(\mathrm{D})\}\varepsilon^{kf(\mathrm{D})}u,$$

dropping the mark under D, as being no further needed, D everywhere now operating upon all that follows it. Make

$$f(\mathrm{D})=\int\frac{d\mathrm{D}}{\varphi(\mathrm{D})},$$

then

$$f'(\mathrm{D})=\frac{1}{\varphi(\mathrm{D})},$$

and the last equation becomes

$$\varepsilon^{k\int\frac{d\mathrm{D}}{\varphi(\mathrm{D})}}\Big\{\varphi(\mathrm{D})x+\lambda(\mathrm{D})\Big\}u=\Big\{\{\varphi(\mathrm{D})x+\lambda(\mathrm{D})+k\Big\}\varepsilon^{k\int\frac{d\mathrm{D}}{\varphi(\mathrm{D})}}u.$$

Now let

$$\varphi(\mathrm{D})x+\lambda(\mathrm{D})=\varpi',\ \varepsilon^{\int\frac{d\mathrm{D}}{\varphi(\mathrm{D})}}=\tau',$$

which gives

$$\frac{1}{\varphi(\mathrm{D})}=\frac{1}{\tau'}\ \frac{d\tau'}{d\mathrm{D}};$$

and the preceding becomes

$$\tau'^k\varpi'u=(\varpi'+k)\tau'^ku.$$

Change u into $\tau'^{-k}u$, and there results

$$\tau'^k\varpi'\tau'^{-k}u=(\varpi'+k)u,$$

or

$$(\varpi'+k)u=\tau'^k\varpi'\tau'^{-k}u$$

by transposing the members.

From the last equation, by the same course of reasoning by which (*a.*) was established, we find

$$\tau'^{-k}f(\varpi'+k)u=f(\varpi')\tau'^{-k}u. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b.)$$

If in (*a.*) we change x into D and D into x, and also ε into ε^{-1}, we convert (*a.*) into (*b.*); and the same conversion of symbols will change (*b.*) into (*a.*).

Application of the preceding Theorem.

The equations

$$f(\varpi')\varpi'u+pf_{\prime}(\varpi')(\varpi'+nk)\tau'^{-k}u=\mathrm{X},$$

$$f(\varpi')(\varpi'+nk)u+pf_{\prime}(\varpi')\varpi'\tau'^{-k}u=\mathrm{X},$$

$$f(\varpi')\varpi'(\varpi'+k)u+pf_{\prime}(\varpi')(\varpi'+nk)\tau'^{-2k}u=\mathrm{X}, \text{ \&c.}$$

by the assumptions

$$u=(\varpi'+k)\dots(\varpi'+nk)v,$$

$$u=(\varpi'+k)^{-1}\dots(\varpi'+nk)^{-1}v,$$

$$u=(\varpi'+2k)\dots(\varpi'+(n+1)k)v, \text{ \&c.}$$

will reduce to

$$f(\varpi')v+pf_{,}(\varpi')\tau'^{-k}v=\mathrm{P}'\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X},$$

$$f(\varpi')v+pf_{,}(\varpi')\tau'^{-k}v=\mathrm{P}'\begin{Bmatrix}(n-1)k\\k\end{Bmatrix}\mathrm{X},$$

$$f(\varpi')(\varpi'+(n+1)k)v+pf_{,}(\varpi')\tau'^{-2k}v=\mathrm{P}'\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X},\ \&c.$$

respectively, the reductions being made by the theorem (*b.*).

But these equations and every step of their reduction may be derived immediately from (1.), (3.), &c., and their reductions by the conversion of symbols before mentioned, which is not a little remarkable. Hence we may derive the solutions of the one series from those of the other merely by the interchange of symbols.

In the equations of which we are now treating, $\varphi(\mathrm{D})$ and $\lambda(\mathrm{D})$ must be rational functions of D; and we must also have $\tau'^{-k}=\chi(\mathrm{D})$, a rational function. Therefore we must have

$$\frac{1}{\varphi(\mathrm{D})}=-\frac{\chi'(\mathrm{D})}{k\chi(\mathrm{D})},$$

and

$$\varphi(\mathrm{D})=-\frac{k\chi(\mathrm{D})}{\chi'(\mathrm{D})}.$$

In the values of u we have operating factors of the form

$$(\varpi'+rk)^{-1}=(\varphi(\mathrm{D})x+\lambda(\mathrm{D})+rk)^{-1}=\left(x+\frac{\lambda(\mathrm{D})+rk}{\varphi(\mathrm{D})}\right)^{-1}\varphi(\mathrm{D})^{-1}=\varepsilon^{\int\frac{\lambda(\mathrm{D})+rk}{\varphi(\mathrm{D})}d\mathrm{D}}x^{-1}\varepsilon^{-\int\frac{\lambda(\mathrm{D})+rk}{\varphi(\mathrm{D})}d\mathrm{D}}\varphi(\mathrm{D})^{-1}$$

by a well-known theorem due to Mr. Boole. Now in order that these may be practicable in finite terms, or as it is usual to say, capable of interpretation, we must have

$$\varepsilon^{\int\frac{\lambda(\mathrm{D})}{\varphi(\mathrm{D})}d\mathrm{D}}=\Phi(\mathrm{D})\varepsilon^{m\mathrm{D}},$$

$\Phi(\mathrm{D})$ being a rational function of D, and m being any constant, positive or negative, or nothing. This is the most general form possible, and it gives

$$\frac{\lambda(\mathrm{D})}{\varphi(\mathrm{D})}=\frac{m\Phi(\mathrm{D})+\Phi'(\mathrm{D})}{\Phi(\mathrm{D})},$$

and

$$\lambda(\mathrm{D})=\frac{\varphi(\mathrm{D})}{\Phi(\mathrm{D})}(m\Phi(\mathrm{D})+\Phi'(\mathrm{D})).$$

The expression $\varepsilon^{\int\frac{rk}{\varphi(\mathrm{D})}d\mathrm{D}}$ has been rendered practicable in making τ'^{-k} so.

The only other operating factor which we have to consider is

$$(\varpi'+h+p\tau'^{-k})^{-1},$$

h being some constant. Now putting for τ'^{-k} its value before found, this will reduce to

$$\left\{x+\frac{\lambda(\mathrm{D})+h+p\chi(\mathrm{D})}{\varphi(\mathrm{D})}\right\}^{-1}\varphi(\mathrm{D})^{-1}.$$

The exponentials depending on $\frac{\lambda(\mathrm{D})}{\varphi(\mathrm{D})}$ and $\frac{h}{\varphi(\mathrm{D})}$ have been considered, and it only remains to consider

$$\varepsilon^{p\int\frac{\chi(\mathrm{D})}{\varphi(\mathrm{D})}d\mathrm{D}}=\varepsilon^{-\frac{p}{k}\int\chi'(\mathrm{D})d\mathrm{D}}=\varepsilon^{-\frac{p}{k}\chi(\mathrm{D})}$$

by substituting for $\frac{1}{\varphi(\mathrm{D})}$ its value. But $\varepsilon^{-\frac{p}{k}\chi(\mathrm{D})}$ cannot be interpreted except when $\chi(\mathrm{D})=q\mathrm{D}$. We have therefore, finally,

$$\tau'^{-k}=q\mathrm{D},\ \varphi(\mathrm{D})=-k\mathrm{D},\ \lambda(\mathrm{D})=-\frac{k\mathrm{D}}{\Phi(\mathrm{D})}(m\Phi(\mathrm{D})+\Phi'(\mathrm{D})).$$

This result narrows very much the limits of the practicable cases.

We may however obtain a small increase of generality by making $\chi(\mathrm{D})=q\mathrm{D}+r$. There is nothing to prevent this, since

$$\varepsilon^{-\frac{p}{k}(q\mathrm{D}+r)}=\varepsilon^{-\frac{pr}{k}}\varepsilon^{-\frac{pq}{k}\mathrm{D}},$$

which makes no change in the interpretation of the results, the only difference which it occasions being the introduction of the constant quantity $\varepsilon^{-\frac{pr}{k}}$ into the value of u where we should otherwise have unity in its place. Thus we shall have

$$\tau'^{-k}=q\mathrm{D}+r,\ \varphi(\mathrm{D})=-k\left(\mathrm{D}+\frac{r}{q}\right),\ \lambda(\mathrm{D})=-k\left(\mathrm{D}+\frac{r}{q}\right)\left(m+\frac{\Phi'(\mathrm{D})}{\Phi(\mathrm{D})}\right);$$

which values give

$$\varpi'=-k\left(\mathrm{D}+\frac{r}{q}\right)\left(x+m+\frac{\Phi'(\mathrm{D})}{\Phi(\mathrm{D})}\right).$$

By the conversion of symbols we derive from (9.),

$$\varpi'(\varpi'+a)u+p(\varpi'+nk)\tau'^{-k}u=\mathrm{X},$$

$$u=\mathrm{P}'\begin{Bmatrix}nk\\k\end{Bmatrix}(\varpi'+a+p\tau'^{-k})^{-1}\mathrm{P}'\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X},$$

which by putting for τ'^{-k} its value becomes

$$\varpi'(\varpi'+a)u+p(\varpi'+nk)(q\mathrm{D}+r)u=\mathrm{X} \quad \dots\dots\dots\dots \quad (15.)$$

$$u=\mathrm{P}'\begin{Bmatrix}nk\\k\end{Bmatrix}(\varpi'+pq\mathrm{D}+pr+a)^{-1}\mathrm{P}'\begin{Bmatrix}nk\\0\end{Bmatrix}^{-1}\mathrm{X}.$$

From (11.) we derive in like manner

$$(\varpi'+a)(\varpi'+nk)u+p\varpi'(q\mathrm{D}+r)u=\mathrm{X} \quad \dots\dots\dots \quad (16.)$$

$$u=\mathrm{P}'\begin{Bmatrix}nk\\k\end{Bmatrix}^{-1}(\varpi'+pq\mathrm{D}+pr+a)^{-1}\mathrm{P}'\begin{Bmatrix}(n-1)k\\k\end{Bmatrix}\mathrm{X}.$$

But (10.) and (12.) treated thus would lead to equations of the third order; and as we cannot notice those of all orders, we shall pass these by.

It would render the values of u too long and complex to substitute for ϖ' its value and reduce them further. But this is unnecessary, since the method of doing it has been made sufficiently plain, and indeed is well understood. If we would reduce these equations to the ordinary form, it can easily be effected by the formula

$$f(\mathrm{D})=f(\mathrm{D}_1+\mathrm{D}_2)=f(\mathrm{D}_1)+\mathrm{D}_2f'(\mathrm{D}_1)+\tfrac{1}{2}\mathrm{D}_2^2f''(\mathrm{D})+\&\text{c.},$$

where D_1 operates upon u, D_2 upon x. Thus we find

$$\varphi(D)xu = x\varphi(D)u + \varphi'(D)u$$

$$\varphi(D)x\varphi(D)xu = x^2\varphi(D)^2u + 3x\varphi(D)\varphi'(D)u + \varphi(D)\varphi''(D)u + \varphi'(D)^2u.$$

But this reduction would lead to resulting equations of considerable length, unless we give to $\Phi(D)$ a particular form. This form should be such that negative powers of D may disappear. Or we may make $u = \Phi(D)z$, and so take away such powers, and at the same time may introduce more arbitrary constants into the equation. Thus we should find integrable equations of the second order, having coefficients of the form $a + bx + cx^2$, of considerable generality, owing to the large number of constants which they would contain. The method will be found on trial well adapted to the integration of such equations.

By changing k into $2k$, we shall have

$$\tau'^{-2k} = qD + r,\ \varphi(D) = -2k\left(D + \frac{r}{q}\right),\ \lambda(D) = -2k\left(D + \frac{r}{q}\right)\left(m + \frac{\Phi'(D)}{\Phi(D)}\right),$$

$$\varpi' = -2k\left(D + \frac{r}{q}\right)\left(x + m + \frac{\Phi'(D)}{\Phi(D)}\right).$$

With these values we derive from (14.),

$$(\varpi' + nk)(\varpi' + nk + k)u + p\varpi'(qD + r)u = X \quad \ldots\ldots\ldots\ldots \quad (17.)$$

$$u = P'\begin{Bmatrix}(n+1)k \\ 2k\end{Bmatrix}^{-1}\{\varpi' + pqD + pr + k\}^{-1}P'\begin{Bmatrix}(n-1)k \\ k\end{Bmatrix}X.$$

Other examples might be given under this head, but I shall now proceed to the solution of two equations somewhat similar to some of those which have been given, but which cannot be solved in the same manner.

III. THIRD AND FOURTH GENERAL THEOREMS.

Make

$$\varrho = \varepsilon^{\int \frac{\lambda}{\varphi} dx},\ \pi_m = \varphi D + \Psi + m\lambda,$$

and consequently

$$\pi_n = \varphi D + \Psi + n\lambda.$$

We easily verify the equation

$$\varrho^n \pi_{m+n} u = \pi_m \varrho^n u$$

by substituting for ϱ and π_{m+n}, π_m their values, and performing the operations indicated in the result. Therefore by the process followed in the investigation of (*a.*), we find

$$\varrho^n f(\pi_{m+n})u = f(\pi_m)\varrho^n u \quad \ldots\ldots\ldots\ldots \quad (c.)$$

To establish the other general theorem, we make

$$\varrho' = \varepsilon^{\int \frac{\lambda(D)}{\varphi(D)} dD},\quad \pi'_m = \varphi(D)x + \Psi(D) + m\lambda(D),$$

and therefore also

$$\pi'_n = \varphi(D)x + \Psi(D) + n\lambda(D).$$

But we have found

$$\varepsilon^{nf(\mathrm{D})}=\{1+n\mathrm{D}_2 f'(\mathrm{D}_1)+\}\varepsilon^{nf(\mathrm{D}_1)}.$$

Operating with both members of this on

$$\{\varphi(\mathrm{D})x+\Psi(\mathrm{D})+m\lambda(\mathrm{D})\}u,$$

we find

$$\varepsilon^{nf(\mathrm{D})}\{\varphi(\mathrm{D})x+\Psi(\mathrm{D})+m\lambda(\mathrm{D})\}u=\{\varphi(\mathrm{D})x+\Psi(\mathrm{D})+m\lambda(\mathrm{D})+n\varphi(\mathrm{D})f'(\mathrm{D})\}\varepsilon^{nf(\mathrm{D})}u,$$

dropping the mark under D as no longer needed.

Make

$$f(\mathrm{D})=\int\frac{\lambda(\mathrm{D})}{\varphi(\mathrm{D})}d\mathrm{D},$$

then

$$f'(\mathrm{D})=\frac{\lambda(\mathrm{D})}{\varphi(\mathrm{D})},\ \varphi(\mathrm{D})f'(\mathrm{D})=\lambda(\mathrm{D}).$$

Substituting this value of $f'(\mathrm{D})$ in the last equation, the result will be equivalent to

$$\varrho'^{n}\pi'_{m}u=\pi'_{m+n}\varrho'^{n}u.$$

Change u into $\varrho'^{-n}u$, and transpose the members, and we have

$$\pi'_{m+n}u=\varrho'^{n}\pi'_{m}\varrho'^{-n}u.$$

Therefore, as before, we shall have

$$\varrho'^{-n}f(\pi'_{m+n})u=f(\pi'_{m})\varrho'^{-n}u. \quad \ldots\ldots\ldots\ldots \quad (d.)$$

By the interchange of the symbols x and D, the two general theorems (*c.*) and (*d.*) may be converted the one into the other, ε at the same time being changed into ε^{-1}.

Before we can employ these theorems in the way intended, we must find the relations between the arbitrary functions required in order that two others may subsist. The first of which is

$$\pi_m\pi_n u=\pi_n\pi_m u+(n-m)a\varrho u. \quad \ldots\ldots\ldots\ldots \quad (e.)$$

With the values given of π_m and π_n, we easily find that

$$\pi_m\pi_n u=\pi_n\pi_m u+(n-m)\varphi\lambda' u.$$

Therefore we must have

$$a\varrho=\varphi\lambda',\ \text{or}\ a\varepsilon^{\int\frac{\lambda}{\varphi}dx}=\varphi\lambda'.$$

Passing to the logarithms of both members,

$$\log a+\int\frac{\lambda}{\varphi}dx=\log(\varphi\lambda'),$$

and by differentiation

$$\frac{\lambda}{\varphi}dx=\frac{d(\varphi\lambda')}{\varphi\lambda'}.$$

Hence we find successively

$$\lambda\lambda' dx=d(\varphi\lambda'),\ \frac{1}{2}d(\lambda^2)=d(\varphi\lambda'),\ b+\frac{1}{2}\lambda^2=\varphi\lambda',\ \text{and}\ \frac{1}{\varphi}=\frac{\lambda'}{b+\frac{1}{2}\lambda^2},$$

which is the required relation or condition.

From the last we find

$$\int\frac{\lambda}{\varphi}dx=\int\frac{\lambda d\lambda}{b+\frac{1}{2}\lambda^2}=\log\left(b+\frac{1}{2}\lambda^2\right)+\log c.$$

We easily find $c=\frac{1}{a}$, therefore $\varrho=\frac{b+\frac{1}{2}\lambda^2}{a}\cdot$

The other condition alluded to is

$$\pi'_m\pi'_n u=\pi'_n\pi'_m u+(n-m)a\varrho'^{-1}u. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (f.)$$

From the values of π'_m, π'_n, we find

$$\pi'_m\pi'_n u=\pi'_n\pi'_m u+(m-n)\varphi(\mathrm{D})\lambda'(\mathrm{D}).$$

Therefore we must have

$$-a\varrho'^{-1}=\varphi(\mathrm{D})\lambda'(\mathrm{D}),\text{ or }-a\varepsilon^{-\int\frac{\lambda(\mathrm{D})}{\varphi(\mathrm{D})}d\mathrm{D}}=\varphi(\mathrm{D})\lambda'(\mathrm{D})\,;$$

and as in the former case,

$$-\frac{\lambda(\mathrm{D})}{\varphi(\mathrm{D})}d\mathrm{D}=\frac{d\{\varphi(\mathrm{D})\lambda'(\mathrm{D})\}}{\varphi(\mathrm{D})\lambda'(\mathrm{D})},\ -\lambda(\mathrm{D})d\lambda(\mathrm{D})=d\{\varphi(\mathrm{D})\lambda'(\mathrm{D})\}.$$

Therefore, also,

$$b-\frac{1}{2}\lambda(\mathrm{D})^2=\varphi(\mathrm{D})\lambda'(\mathrm{D}),\text{ and }\frac{1}{\varphi(\mathrm{D})}=\frac{\lambda'(\mathrm{D})}{b-\frac{1}{2}\lambda(\mathrm{D})^2},$$

which is the required relation between $\varphi(\mathrm{D})$ and $\lambda(\mathrm{D})$.

Also

$$-\int\frac{\lambda(\mathrm{D})}{\varphi(\mathrm{D})}d\mathrm{D}=\log\left(\frac{b-\frac{1}{2}\lambda(\mathrm{D})^2}{c}\right),$$

where we easily perceive that $c=-a$. Whence $\varrho'=\frac{a}{\frac{1}{2}\lambda(\mathrm{D})^2-b}\cdot$

Application of the four last Theorems and Formulæ.

Let

$$\pi_m\pi_n u+p\varrho u=\mathrm{X}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18.)$$

A single case of this equation was solved by Mr. Boole in No. 7, New Series of the Cambridge Mathematical Journal, the quantities φ and λ being given functions of the independent variable, and having a given relation, Ψ being nothing. In the Philosophical Magazine, vol. xxxii. p. 257, I gave two similar solutions, but contrived to introduce an arbitrary function of x, by which the solution was very greatly extended. Here that method is superseded and the solution rendered much more general. To solve the above, make $u=\pi_{m+1}u_1$; then

$$\pi_m\pi_n\pi_{m+1}u_1+p\varrho\pi_{m+1}u_1=\mathrm{X}\text{ by substitution,}$$

$$\pi_m\pi_n\pi_{m+1}u_1+p\pi_m\varrho u_1=\mathrm{X}\text{ by }(c.),$$

$$\pi_n\pi_{m+1}u_1+p\varrho u_1=\pi_m^{-1}\mathrm{X},$$

$$\pi_{m+1}\pi_n u_1+p_1\varrho u_1=\pi_m^{-1}\mathrm{X}\text{ by }(e.),\ p_1=p-a(n-m-1).$$

After i transformations, we have

$$\pi_{m+i}\pi_n u_i + p_i \varrho u_1 = \pi_{m+i-1}^{-1} \ldots\ldots \pi_m^{-1} X.$$

If $p_i=0$, or $p=ia\left(n-m-\frac{i+1}{2}\right)$, the equation is solved, and we have

$$u_i = \pi_n^{-1}\pi_{m+i}^{-1} \ldots\ldots \pi_m^{-1} X.$$

From this we easily find u. The success of the method, it will be seen, depends upon the value of p.

Other cases and solutions may be seen in the Philosophical Magazine in the article before mentioned, but they cannot be given here.

Reduced to the ordinary form, (18.) becomes

$$\varphi^2 D^2 u + \varphi(\varphi' + 2\Psi + (m+n)\lambda) D u + (\varphi(\varphi' + n\lambda') + (\Psi + m\lambda)(\Psi + n\lambda) + p\varrho) u = X.$$

If we were to substitute for φ and ϱ their values, this would become very complicated. We see that it differs considerably in form from the preceding examples which have been thus reduced.

There is one equation bearing some analogy to that which has just been solved which deserves to be noticed here, although its solution must be effected by a very different process. It is

$$\pi_m \pi_n u + p\varrho^{2(n-m)} u = X. \quad \ldots\ldots\ldots\ldots \quad (19.)$$

By (c.) this may be put under the form

$$\pi_m \varrho^{m-n} \pi_m \varrho^{n-m} u + p\varrho^{2(n-m)} u = X.$$

Make $u=\varrho^{2(m-n)}v$, and the last, by substituting this value, will become

$$\pi_m \varrho^{m-n} \pi_m \varrho^{m-n} v + pv = X.$$

Now let $\pi_m \varrho^{m-n} = \tau$, and the preceding will be reduced to

$$(\tau^2 + p)v = X.$$

Whence

$$v = (\tau^2 + p)^{-1} X = \frac{A}{\tau - p^{\frac{1}{2}}\sqrt{-1}} X - \frac{A}{\tau + p^{\frac{1}{2}}\sqrt{-1}} X,$$

where

$$A = \frac{1}{2p^{\frac{1}{2}}\sqrt{-1}}.$$

If $v=v_1+v_2$, we may evidently make

$$(\tau - p^{\frac{1}{2}}\sqrt{-1})v_1 = AX, \quad (\tau + p^{\frac{1}{2}}\sqrt{-1})v_2 = -AX;$$

for these lead to the same result. And thus v is found from two equations of a lower order than the given equation.

If we now put for τ its value in the two last equations, we shall have

$$\pi_m \varrho^{m-n} v_1 - p^{\frac{1}{2}}\sqrt{-1}\, v_1 = AX, \quad \pi_m \varrho^{m-n} v_2 + p^{\frac{1}{2}}\sqrt{-1}\, v_2 = -AX.$$

If we put $\varrho^{m-n}v_1=\omega_1$, $\varrho^{m-n}v_2=\omega_2$, these will take the more convenient form

$$\pi_m\omega_1-p^{\frac{1}{2}}\sqrt{-1}\varrho^{n-m}\omega_1=\mathrm{AX},\ \pi_m\omega_2+p^{\frac{1}{2}}\sqrt{-1}\varrho^{n-m}\omega_2=-\mathrm{AX};$$

which are only of the first order, since π_m is of that order. The equation (19.) may therefore be considered as integrated.

By the conversion of symbols (18.) and (19.) will be changed into

$$\left.\begin{aligned}\pi'_m\pi'_n u+p\varrho'^{-1}u=\mathrm{X},\\ \pi'_m\pi'_n u+p\varrho'^{2(m-n)}u=\mathrm{X}\end{aligned}\right\}\quad\ldots\ldots\ldots\ldots\quad(20.)$$

These may be solved by means of the formulæ (*d.*) and (*f.*) in exactly the same way as (18.) and (19.), and every step of the solution in the one case may be derived from the corresponding step of the solution in the other merely by the conversion of symbols. But every solution of these equations will not be a practicable one, or be susceptible of interpretation in finite terms. The operations π'^{-1}_{m+r} however can be performed if

$$\varepsilon^{\int\left(\frac{\Psi(\mathrm{D})+(m+r)\lambda(\mathrm{D})}{\varphi(\mathrm{D})}\right)d\mathrm{D}}=\chi(\mathrm{D})\varepsilon^{q\mathrm{D}},$$

$\chi(\mathrm{D})$ being a rational function of D, and the constant q being positive, negative, or nothing. By differentiating the logarithms of each member relative to D, this will give

$$\frac{\Psi(\mathrm{D})+(m+r)\lambda(\mathrm{D})}{\varphi(\mathrm{D})}=\frac{q\chi(\mathrm{D})+\chi'(\mathrm{D})}{\chi(\mathrm{D})},$$

or

$$\frac{\Psi(\mathrm{D})+(m+r)\lambda(\mathrm{D})}{b-\frac{1}{2}\lambda(\mathrm{D})^2}=\frac{q\chi(\mathrm{D})+\chi'(\mathrm{D})}{\chi(\mathrm{D})\lambda'(\mathrm{D})},$$

by putting for $\frac{1}{\varphi(\mathrm{D})}$ its value, and dividing the equation by $\lambda'(\mathrm{D})$. Therefore

$$\Psi(\mathrm{D})=\frac{q\chi(\mathrm{D})+\chi'(\mathrm{D})}{\chi(\mathrm{D})\lambda'(\mathrm{D})}\Big(b-\frac{1}{2}\lambda(\mathrm{D})^2\Big)-(m+r)\lambda(\mathrm{D}).$$

Such is the value which $\Psi(\mathrm{D})$ must have in order that the solution may be practicable, $\lambda(\mathrm{D})$ being at the same time a rational function of D.

The value of $\Psi(\mathrm{D})$ is too complex for practical utility. But if we make

$$b=\frac{1}{2}c^2,\ \lambda(\mathrm{D})=a\mathrm{D}+c,$$

we shall have

$$\frac{b-\frac{1}{2}\lambda(\mathrm{D})^2}{\lambda'(\mathrm{D})}=-\frac{1}{2}\mathrm{D}(a\mathrm{D}+2c).$$

If therefore $\chi(\mathrm{D})=a\mathrm{D}+2c$, then we find

$$\Psi(\mathrm{D})=-\frac{1}{2}aq\mathrm{D}^2-\Big(am+ar+cq+\frac{1}{2}a\Big)\mathrm{D}-(cm+cr).$$

But if $\chi(\mathrm{D})=\frac{1}{2}\mathrm{D}$, we shall have

$$\Psi(\mathrm{D})=-\tfrac{1}{2}aq\mathrm{D}^2-\left(am+ar+cq+\tfrac{1}{2}a\right)\mathrm{D}-(cm+cr+c).$$

With either of these values, and by suitably assuming m and n, we may find convenient practicable forms for both the equations (20.). And perhaps we may succeed with other assumptions. If we admit complex forms, we may have them in abundance.

IV. SOLUTION OR REDUCTION OF ANOTHER SERIES OF EQUATIONS.

The equations here treated of are generalizations and extensions of one solved by Mr. Boole in the Cambridge Mathematical Journal, No. 1, New Series. In that equation the coefficients are integer functions of x, here they may be any functions of that quantity consistent with the conditions of integrability. Also the symbol D is replaced by ϖ, and arbitrary functions of this last are introduced.

In order to abridge I shall write ϖ_a for $\varpi+a$, and $f(\varpi)$ will denote any rational function of ϖ. This being premised, let

$$f(\varpi)f(\varpi-k)\varpi(\varpi+k)u+p\varpi_a(\varpi_a+(2n+1)k)\tau^{2k}u=\mathrm{X}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (21.)$$

Assume

$$u=(\varpi_a+3k)(\varpi_a+5k)\ldots.(\varpi_a+(2n+1)k)v,$$

the common difference of the factors being here $2k$. Then by (a.) we shall have

$$(\varpi_a+(2n+1)k)\tau^{2k}u=(\varpi_a+k)\ldots.(\varpi_a+(2n+1)k)\tau^{2k}v.$$

Substituting these values and reducing the result, we find

$$f(\varpi)f(\varpi-k)\varpi(\varpi+k)v+p\varpi_a(\varpi_a+k)\tau^{2k}v=\mathrm{P}\begin{Bmatrix}(2n+1)k\\3k\end{Bmatrix}\mathrm{X}_1,$$

where the a is suppressed in the factorial of the second member for brevity. If we put

$$f(\varpi)^{-1}f(\varpi-k)^{-1}\varpi^{-1}(\varpi+k)^{-1}\mathrm{P}\begin{Bmatrix}(2n+1)k\\3k\end{Bmatrix}^{-1}\mathrm{X}=\mathrm{X}_1,$$

we have

$$v+p\frac{(\varpi_a+k)\varpi_a}{f(\varpi)(\varpi+k)f(\varpi-k)\varpi}\tau^{2k}v=\mathrm{X}_1,$$

or

$$v+p\left(\frac{\varpi_a+k}{f(\varpi)(\varpi+k)}\right)\tau^k\left(\frac{\varpi_a+k}{f(\varpi)(\varpi+k)}\right)\tau^k v=\mathrm{X}_1, \text{ by } (a.).$$

Make

$$\left(\frac{\varpi_a+k}{f(\varpi)(\varpi+k)}\right)\tau^k=\varrho,$$

and the last becomes

$$v+p\varrho^2v=\mathrm{X}_1.$$

The mode of treating this has been already explained. By it the proposed is made to depend upon two others, each of which is of an order only half as high. In certain cases therefore this reduction amounts to a solution.

Let us next take the equation

$$\varpi_a(\varpi_a+(2n+1)k)u+pf(\varpi)f(\varpi-k)\varpi(\varpi+k)\tau^{2k}u=\mathrm{X}, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (22.)$$

the arbitrary functions being put in the second term, for this only amounts to changing them and X.

Assume

$$u=(\varpi_a+3k)^{-1}\ldots\ldots(\varpi_a+(2n+1)k)^{-1}v.$$

Proceeding exactly as heretofore, we find

$$v+p\frac{f(\varpi)(\varpi+k)f(\varpi-k)\varpi}{(\varpi_a+k)\varpi_a}\tau^{2k}v=\mathrm{X}_1,$$

if

$$\mathrm{X}_1=\varpi_a^{-1}(\varpi_a+k)^{-1}\mathrm{P}\left\{\begin{matrix}(2n-1)k\\ k\end{matrix}\right\}\mathrm{X}.$$

Making

$$\left(\frac{f(\varpi)(\varpi+k)}{\varpi_a+k}\right)\tau^k=\varrho,$$

by (*a.*) the last becomes

$$v+p\varrho^2v=\mathrm{X}_1.$$

In the next two examples we shall put the equations under a somewhat different form, on account of their complexity. Suppose

$$u+\frac{\varpi_a(\varpi_a+k)(\varpi_a+(3n+2)k)}{f(\varpi)f(\varpi-k)f(\varpi-2k)\varpi(\varpi+k)(\varpi+2k)}p\tau^{3k}u=\mathrm{X}.$$

Here we assume

$$u=(\varpi_a+5k)\ldots\ldots(\varpi_a+(3n+2)k)v,$$

the common difference of the factors being $3k$.

If

$$\mathrm{X}_1=\mathrm{P}\left\{\begin{matrix}(3n+2)k\\ 5k\end{matrix}\right\}^{-1}\mathrm{X},\quad \varrho=\left(\frac{\varpi_a+2k}{f(\varpi)(\varpi+2k)}\right)\tau^k;$$

we shall have in this case

$$v+p\varrho^3v=\mathrm{X}_1,$$

which may be replaced by three equations, each containing the first power only of ϱ.

As a last example let

$$u+\frac{f(\varpi)f(\varpi-k)f(\varpi-2k)\varpi(\varpi+k)(\varpi+2k)}{\varpi_a(\varpi_a+k)(\varpi_a+(3n+2)k)}p\tau^{3k}u=\mathrm{X}.$$

Here

$$u=(\varpi_a+5k)^{-1}\ldots\ldots(\varpi_a+(3n+2)k)^{-1}v,\quad \varrho=\left(\frac{f(\varpi)(\varpi+2k)}{\varpi_a+2k}\right)\tau^k,$$

and also

$$v+p\varrho^3v=\mathrm{X}_1.$$

This series of equations may be continued at pleasure; and it is obvious that in the whole series, if we change ϖ into ϖ', and τ into τ'^{-1}, the resulting equations may be reduced by (*b.*) exactly as these have been by (*a.*), and that the solutions or reductions of the one series may be obtained from those of the other by the conversion of symbols.

Mr. **Boole**'s general equation

$$X=u+af(D)\varepsilon^{\theta}u+bf(D)f(D-k)\varepsilon^{2\theta}u+\ldots..$$

may be generalized and extended in the same way. Thus if

$$X=u+af(\varpi)\tau^{k}u+bf(\varpi)f(\varpi-k)\tau^{2k}u+\ldots..,$$

or

$$X=u+af(\varpi')\tau'^{-k}u+bf(\varpi')f(\varpi'-k)\tau'^{-2k}u+\ldots.,$$

by making $\varrho=f(\varpi)\tau^{k}$ in the first, and $\varrho'=f(\varpi')\tau'^{-k}$ in the second, we shall have

$$X=u+a\varrho u+b\varrho^{2}u+\ldots=(1-p_{1}\varrho)(1-p_{2}\varrho)\ldots.u,$$

$$X=u+a\varrho'u+b\varrho'^{2}u+\ldots.=(1-p_{1}\varrho')(1-p_{2}\varrho')\ldots.u.$$

And thus each equation, by the method explained further back, will be reduced to a number of others, each of which is much more simple than the proposed.

It must be observed, that the method which has been applied to the solution of each particular class of equations will not apply to either of the other classes. We see the same thing when employing other methods, and we see no reason to suppose that our means of integrating equations will ever be greatly extended otherwise than by the multiplication or aggregation of particular methods. Such methods therefore ought not to be considered as possessing little interest. The same thing may be inferred from the various conditions of integrability at which we arrive in those cases where we can treat the same sort of equations by different methods.

Some of the examples which have been given in this paper, when reduced to the ordinary form, are very complex; but when particular forms are assigned to the arbitrary functions, results sufficiently simple may be obtained. If we will accept none but such as at first sight present themselves under a very simple form, we must not expect any great extension of our present scanty means of integration; for these equations are usually very easily integrated. The following example may serve as an illustration.

The theorem

$$\phi D^{n}u=D^{n}\phi u-nD^{n-1}\phi'u+\frac{n(n-1)}{2}D^{n-2}\phi''u-\text{ \&c.}$$

is easily verified by performing the operations D^{n}, D^{n-1}, &c. in the second member by means of the formula

$$D^{n}=D_{1}^{n}+nD_{2}D_{1}^{n-1}+\frac{n(n-1)}{2}D_{2}^{2}D_{1}^{n-2}+\text{ \&c.}$$

Now let there be given the equation

$$X=\Psi u+\Psi_{1}Du+\Psi_{2}D^{2}u+\Psi_{3}D^{3}u+\ldots..$$

and let this, by the preceding theorem, be transformed into

$$X=\Phi u+D\Phi_{1}u+D^{2}\Phi_{2}u+D^{3}\Phi_{3}u+\ldots..$$

We shall have

$$\Phi=\Psi-\Psi_{1}'+\Psi_{2}''-\Psi_{3}'''+\ldots$$

$$\Phi_{1}=\Psi_{1}-2\Psi_{2}'+3\Psi_{3}''-\ldots.$$

$$\Phi_{2}=\Psi_{2}-3\Psi_{3}'+\ldots..$$

$$\Phi_{3}=\Psi_{3}-\ldots..\text{ \&c.}$$

If $\Phi=0$, the equation is integrable once, and we shall have

$$D^{-1}X=\Phi_1u+D\Phi_2u+D^2\Phi_3u+\dots.$$

If both $\Phi=0$, and $\Phi_1=0$, it is integrable twice, and we have

$$D^{-2}X=\Phi_2u+D\Phi_3u+\dots.$$

Let us take as an example the following equation of the second order,

$$\Psi_2D^2u+\Psi_1Du+(\Psi_1'-\Psi_2'')u=X.$$

The transformed gives

$$D\Phi_2u+\Phi_1u=D^{-1}X,$$

or

$$\Psi_2Du+(\Psi_1-\Psi_2')u=D^{-1}X,$$

and

$$u=\left(D+\frac{\Psi_1-\Psi_2'}{\Psi_2}\right)^{-1}\Psi_2^{-1}D^{-1}X=\Psi_2\varepsilon^{-\int\frac{\Psi_1}{\Psi_2}dx}D^{-1}\Psi_2^{-2}\varepsilon^{\int\frac{\Psi_1}{\Psi_2}dx}D^{-1}X.$$

This example was given by Mr. HARGREAVE in the Philosophical Transactions, 1848.

But the proposed equation may at once be put under the form

$$D\{\Psi_2Du+(\Psi_1-\Psi_2')u\}=X,$$

which is immediately integrable, giving

$$\Psi_2Du+(\Psi_1-\Psi_2')u=D^{-1}X,$$

as before found, but this is far from being a solitary example.

V. FIFTH AND SIXTH GENERAL THEOREMS.

The theorems now to be given bear no resemblance to those which have been heretofore investigated, nor is their mode of application at all similar. Making

$$\varphi\chi'=\chi_1,\ \varphi\chi_1'=\chi_2,\ \varphi\chi_2'=\chi_3,\ \&c.,$$

$$\chi\varpi^nu=\varpi^n\chi u-n\varpi^{n-1}\chi_1u+\frac{n(n-1)}{2}\varpi^{n-2}\chi_2u-\ \&c.\quad\dots\dots\quad (g.)$$

will be verified by putting for ϖ its value $\varphi D+\lambda$, and actually performing the operations denoted by D, which may be readily done by the method which has now been repeatedly explained.

Again, making

$$\varphi(D)\chi'(D)=\chi_1(D),\ \varphi(D)\chi_1'(D)=\chi_2(D),\ \varphi(D)\chi_2'(D)=\chi_3(D),\ \&c.,$$

we shall have

$$\chi(D)\varpi'^nu=\varpi'^n\chi(D)u+n\varpi'^{n-1}\chi_1(D)u+\frac{n(n-1)}{2}\varpi'^{n-2}\chi_2(D)u+\&c.\quad\dots\quad (h.)$$

This also may be verified by putting for ϖ' its value $\varphi(D)x+\lambda(D)$, and performing the operations D, where required, by the formula

$$f(D)=f(D_1)+D_2f'(D_1)+\tfrac{1}{2}D_2^2f''(D_1)+\ \&c.,$$

and afterwards dropping the marks of distinction.

Application of the Theorem (g.) *to Integration.*

To apply the theorem (*g.*), let us suppose that we have given the equation

$$X=\Psi u+\Psi^1\varpi u+\Psi^2\varpi^2 u+\text{ \&c.} \qquad (23.)$$

Let this by (*g.*) be transformed into

$$X=\Phi u+\varpi\Phi_1 u+\varpi^2\Phi_2 u+\text{ \&c.}$$

We shall have

$$\Phi=\Psi-\Psi^1_1+\Psi^2_2-\Psi^3_2+\dots$$

$$\Phi_1=\Psi^1-2\Psi^2_1+3\Psi^3_2-\dots.$$

$$\Phi_2=\Psi^2-3\Psi^3_1+\dots..$$

$$\Phi_3=\Psi^3-\dots.\text{\&c.}$$

The figure at the top of Ψ denotes the place of the term in the given equation, that at the bottom marks the term in (*g.*) corresponding to it*. By going a little into the operations, the meaning of these symbols will be easily understood.

If $\Phi=0$, or $\Psi=\Psi^1_1-\Psi^2_2+\dots$ the equation thus transformed will be integrable once, and we shall have

$$\varpi^{-1}X=\Phi_1 u+\varpi\Phi_2 u+\varpi^2\Phi_3 u+\text{\&c.}$$

If, moreover, $\Phi_1=0$, it will be twice integrable.

Let us take as a more particular example the equation

$$\Psi^2\varpi^2 u+\Psi^1\varpi u+(\Psi^1_1-\Psi^2_2)u=X,$$

which is integrable because $\Phi=0$. Putting for Ψ^1_1, Ψ^2_2 their values, this becomes

$$\Psi^2\varpi^2 u+\Psi^1\varpi u+\varphi(\Psi^{1\prime}-\varphi'\Psi^{2\prime}-\varphi\Psi^{2\prime\prime})u=X. \qquad (24.)$$

The transformed equation will be

$$\varpi^2\Phi_2 u+\varpi\Phi_1 u=X,$$

or

$$\varpi\Phi_2 u+\Phi_1 u=\varpi^{-1}X;$$

which by substituting for ϖ its value, is easily reduced to

$$Du+\left(\frac{\Phi_2'}{\Phi_2}+\frac{\lambda}{\varphi}+\frac{\Phi_1}{\varphi\Phi_2}\right)u=(\varphi\Phi_2)^{-1}\varpi^{-1}X.$$

In order to abridge, make

$$\frac{\Phi_2'}{\Phi_2}+\frac{\lambda}{\varphi}+\frac{\Phi_1}{\varphi\Phi_2}=\frac{\lambda}{\varphi}+\frac{\Psi^1}{\varphi\Psi^2}-\frac{\Psi^{2\prime}}{\Psi^2}=\theta;$$

then the last becomes

$$(D+\theta)u=(\varphi\Psi^2)^{-1}\varpi^{-1}X,$$

which gives

$$u=(D+\theta)^{-1}(\varphi\Psi^2)^{-1}\varpi^{-1}X,$$

or

$$u=\varepsilon^{-\int\theta dx}D^{-1}\varepsilon^{\int\theta dx}(\varphi\Psi^2)^{-1}\varepsilon^{-\int\frac{\lambda}{\varphi}dx}D^{-1}\varepsilon^{\int\frac{\lambda}{\varphi}dx}\varphi^{-1}X.$$

---

* The figures at the top of Ψ are not exponents of powers, but distinct functional marks.

If (24.) be reduced to the ordinary form, it becomes

$$D^2u+\left(\frac{\varphi'+2\lambda}{\varphi}+\frac{\Psi^1}{\varphi\Psi^2}\right)Du+\left(\frac{\varphi\lambda'+\lambda^2}{\varphi^2}+\frac{\Psi'(\varphi+\lambda)}{\varphi^2\Psi^2}+\frac{\Psi^{1\prime}-\varphi'\Psi^{2\prime}-\varphi\Psi^{2\prime\prime}}{\varphi\Psi^2}\right)u=\frac{X}{\varphi^2\Psi^2}.$$

This would give a very large number of integrable equations by assigning particular forms to the arbitrary functions φ, λ, Ψ^1, and Ψ^2. And indeed every one of the equations treated of in this paper, by giving particular forms to the arbitrary functions, would furnish a large number of particular ones. This circumstance makes the chance of our being able to put a given equation under some one of these forms the greater, and consequently in this respect enhances the value of the methods employed.

Application of the Theorem (h.).

The equations to be reduced by (*h.*) are of the form

$$X=\Psi(D)u+\Psi^1(D)\varpi'u+\Psi^2(D)\varpi'^2u+\&c. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25.)$$

This is deduced from (23.) by the interchange of the symbols D and x, but the theorems (*g.*) and (*h.*) by which the transformations are effected cannot be thus deduced the one from the other.

The above will be transformed by (*h.*) into

$$X=\Phi(D)u+\varpi'\Phi_1(D)u+\varpi'^2\Phi_2(D)u+\dots..,$$

where

$$\Phi\,(D)=\Psi(D)+\Psi^1_1(D)+\Psi^2_2(D)+\Psi^3_3(D)+\dots$$

$$\Phi_1(D)=\Psi^1(D)+2\Psi^2_1(D)+3\Psi^3_2(D)+\dots.$$

$$\Phi_2(D)=\Psi^2(D)+3\Psi^3_1(D)+\dots..$$

$$\Phi_3(D)=\Psi^3(D)+\dots\&c.$$

If

$$\Phi\,(D)=\Psi(D)+\Psi^1_1(D)+\Psi^2_2(D)+\dots=0,$$

or

$$\Psi\,(D)=-\Psi^1_1(D)-\Psi^2_2(D)-\dots.,$$

we shall have

$$\varpi'^{-1}X=\Phi_1(D)u+\varpi'\Phi_2(D)u+\dots.$$

We might take as examples equations of a higher order than the second, but as these last are of the greater importance I have hitherto selected them, and shall take here the equation

$$\Psi^2(D)\varpi'^2u+\Psi^1(D)\varpi'u-\left(\Psi^1_1(D)+\Psi^2_2(D)\right)u=X,$$

which by putting for $\Psi^1_1(D)$ and $\Psi^2_2(D)$ their values, the figures here at the top and bottom of Ψ signifying the same as in the former case, becomes

$$\Psi^2(D)\varpi'^2u+\Psi^1(D)\varpi'u-\varphi(D)\{\Psi^{1\prime}(D)+\varphi'(D)\Psi^{2\prime}(D)+\varphi(D)\Psi^{2\prime\prime}(D)\}u=X. \quad . \quad (26.)$$

The transformed equation gives

$$\varpi'\Phi_2(D)u+\Phi_1(D)u=\varpi'^{-1}X\,;$$

which, reduced to the most simple form, is equivalent to

$$\phi(\mathrm{D})\Phi_2(\mathrm{D})xu+\{\Phi_1(\mathrm{D})+\lambda(\mathrm{D})\Phi_2(\mathrm{D})-\phi(\mathrm{D})\Phi'_2(\mathrm{D})\}u=\varpi'^{-1}\mathrm{X}.$$

Make

$$\theta(\mathrm{D})=\frac{\Phi_1(\mathrm{D})}{\phi(\mathrm{D})\Phi_2(\mathrm{D})}+\frac{\lambda(\mathrm{D})}{\phi(\mathrm{D})}-\frac{\Phi'_2(\mathrm{D})}{\Phi_2(\mathrm{D})}$$

$$=\frac{\Psi^1(\mathrm{D})}{\phi(\mathrm{D})\Psi^2(\mathrm{D})}+\frac{\lambda(\mathrm{D})}{\phi(\mathrm{D})}+\frac{\Psi^{2\prime}(\mathrm{D})}{\Psi^2(\mathrm{D})}.$$

Substituting this value in the last equation, after dividing both members by $\phi(\mathrm{D})\Phi_2(\mathrm{D})$, or in other words, operating with $\phi(\mathrm{D})^{-1}\Phi_2(\mathrm{D})^{-1}$ on both members, we have

$$\{x+\theta(\mathrm{D})\}u=\{\phi(\mathrm{D})\Phi_2(\mathrm{D})\}^{-1}\varpi'^{-1}\mathrm{X}$$

and

$$u=\{x+\theta(\mathrm{D})\}^{-1}\{\phi(\mathrm{D})\Psi^2(\mathrm{D})\}^{-1}\varpi'^{-1}\mathrm{X},$$

where the value of $\Phi_2(\mathrm{D})$ has been substituted. By further reduction,

$$u=\varepsilon^{\int\theta(\mathrm{D})d\mathrm{D}}x^{-1}\varepsilon^{-\int\theta(\mathrm{D})d\mathrm{D}}\Big(\phi(\mathrm{D})\Psi^2(\mathrm{D})\Big)^{-1}\varepsilon^{\int\frac{\lambda(\mathrm{D})}{\phi(\mathrm{D})}d\mathrm{D}}x^{-1}\varepsilon^{-\int\frac{\lambda(\mathrm{D})}{\phi(\mathrm{D})}d\mathrm{D}}\phi(\mathrm{D})^{-1}\mathrm{X}.$$

The equation itself requires that $\Psi^1(\mathrm{D})$, $\Psi^2(\mathrm{D})$, $\phi(\mathrm{D})$, and $\lambda(\mathrm{D})$ should be rational functions of (D); and that the solution may be practicable, we must have

$$\varepsilon^{\int\frac{\lambda(\mathrm{D})}{\phi(\mathrm{D})}d\mathrm{D}}=\chi(\mathrm{D})\varepsilon^{m\mathrm{D}},$$

$\chi(\mathrm{D})$ being a rational function. Also the term $\frac{\Psi^1(\mathrm{D})}{\phi(\mathrm{D})\Psi^2(\mathrm{D})}$ in the value of $\theta(\mathrm{D})$ requires that we should have

$$\varepsilon^{\int\frac{\Psi^1(\mathrm{D})d\mathrm{D}}{\phi(\mathrm{D})\Psi^2(\mathrm{D})}}=\Phi(\mathrm{D})\varepsilon^{p\mathrm{D}},$$

$\Phi(\mathrm{D})$ being a rational function. These assumptions give, by taking the differentials of their logarithms,

$$\lambda(\mathrm{D})=\phi(\mathrm{D})\Big(m+\frac{\chi'(\mathrm{D})}{\chi(\mathrm{D})}\Big),\ \Psi^1(\mathrm{D})=\phi(\mathrm{D})\Psi^2(\mathrm{D})\Big(p+\frac{\Phi'(\mathrm{D})}{\Phi(\mathrm{D})}\Big).$$

If we were to substitute these values in (26.), we should have a very complex resulting equation; but by giving suitable particular values to the arbitrary functions, and perhaps by changing u into $f(\mathrm{D})z$, giving to $f(\mathrm{D})$ a convenient form, we might obtain resulting equations sufficiently simple, and we might obtain some very general of their kind, remembering to introduce as many arbitrary constants as we can.

Make

$$\chi(\mathrm{D})=\phi(\mathrm{D}),\ \Phi(\mathrm{D})=\Psi^2(\mathrm{D})\,;$$

then

$$\lambda(\mathrm{D})=m\phi(\mathrm{D})+\phi'(\mathrm{D}),\ \Psi^1(\mathrm{D})=\phi(\mathrm{D})\Big(p\Psi^2(\mathrm{D})+\Psi^{2\prime}(\mathrm{D})\Big).$$

With these values (26.) becomes, dropping the figure 2 on the top of Ψ, as being no longer needed,

$$\Psi(\mathrm{D})\varpi'^2u+\phi(\mathrm{D})\Big(p\Psi(\mathrm{D})+\Psi'(\mathrm{D})\Big)\varpi'u-\phi(\mathrm{D})\frac{d}{d\mathrm{D}}\Big\{\phi(\mathrm{D})\Big(p\Psi(\mathrm{D})+2\Psi'(\mathrm{D})\Big)\Big\}u=\mathrm{X},\ . \quad (27.)$$

which is of a remarkable form. Also

$$u=\varphi(\mathrm{D})\Psi(\mathrm{D})^2\varepsilon^{(m+p)\mathrm{D}}x^{-1}\{\varphi(\mathrm{D})\Psi(\mathrm{D})^3\}^{-1}\varepsilon^{-p\mathrm{D}}x^{-1}\varphi(\mathrm{D})^{-2}\varepsilon^{-m\mathrm{D}}\mathrm{X}.$$

The equation (27.) might very well be reduced to the ordinary form without particularizing the arbitrary functions.

If we make

$$\chi(\mathrm{D})=\varphi(\mathrm{D}),\ \Phi(\mathrm{D}=\varphi(\mathrm{D}),$$

and change Ψ^2 into Ψ, we shall have

$$\lambda(\mathrm{D})=m\varphi(\mathrm{D})+\varphi'(\mathrm{D}),\ \Psi^1(\mathrm{D})=\Psi(\mathrm{D})\big(p\varphi(\mathrm{D})+\varphi'(\mathrm{D})\big).$$

With these values (26.) will become, operating with $\Psi(\mathrm{D})^{-1}$ on both members,

$$\varpi'^2u+\big(p\varphi(\mathrm{D})+\varphi'(\mathrm{D})\big)\varpi'u-\frac{\varphi(\mathrm{D})}{\Psi(\mathrm{D})}\frac{d}{d\mathrm{D}}\Big\{p\varphi(\mathrm{D})\Psi(\mathrm{D})+\frac{d}{d\mathrm{D}}\big(\varphi(\mathrm{D})\Psi(\mathrm{D})\big)\Big\}u=\Psi(\mathrm{D})^{-1}\mathrm{X}, \quad (28.)$$

which is of a form not a little singular, and which might be put under the common form, retaining the arbitrary functions.

The value of u in this example is

$$u=\varphi(\mathrm{D})^2\Psi(\mathrm{D})\varepsilon^{(m+p)\mathrm{D}}x^{-1}\{\varphi(\mathrm{D})\Psi(\mathrm{D})\}^{-2}\varepsilon^{-p\mathrm{D}}x^{-1}\varphi(\mathrm{D})^{-2}\varepsilon^{-m\mathrm{D}}\mathrm{X}.$$

In the two last examples we see from the expression of the value of u that they are practicable, or that their solutions can be interpreted.

It may be well to observe, that if we make

$$\varphi(\mathrm{D})=\alpha(\mathrm{D})\chi(\mathrm{D}),\ \Psi^2(\mathrm{D})=\beta(\mathrm{D})\Phi(\mathrm{D}),$$

which give

$$\lambda(\mathrm{D})=\alpha(\mathrm{D})\big(m\chi(\mathrm{D})+\chi'(\mathrm{D})\big),\ \Psi^1(\mathrm{D})=\alpha(\mathrm{D})\beta(\mathrm{D})\chi(\mathrm{D})\big(p\Phi(\mathrm{D})+\Phi'(\mathrm{D})\big);$$

and if we eliminate both $\varphi(\mathrm{D})$ and $\lambda(\mathrm{D})$ from the value of ϖ', and $\Psi^1(\mathrm{D})$, $\Psi^2(\mathrm{D})$ from (26.), our equation by the substitution of these values will then contain the four arbitrary functions $\alpha(\mathrm{D})$, $\beta(\mathrm{D})$, $\chi(\mathrm{D})$ and $\Phi(\mathrm{D})$. These should then be made integer functions of D; but after actual substitution the resulting equation would be very complicated, unless we first give particular forms to the arbitrary functions. If this be done, and as many constants as possible be introduced, particular integrable equations of interest and value, and of sufficient simplicity, may be obtained.

I shall terminate this paper by observing, that in our attempts at integration, we are apt to seek for equations which immediately present themselves under simple forms, and by this means fall chiefly, or altogether, upon such as could previously be integrated.

Gunthwaite Hall, near Barnsley, Yorkshire,
February 4th, 1850.

XX. *Additional Observations on the Diffusion of Liquids.* (*Third Memoir.*)

By Thomas Graham, *Esq., F.R.S., F.C.S. &c.*

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THE experiments on diffusion to be presently described are in continuation of those detailed in my last publication on the subject, the same method of observing being followed without change. The diffusion is generally made from solutions in four different proportions, so as to exhibit pretty fully the characters of the property in question for each salt, so far as is possible at a constant temperature. The salts operated upon are of two bases only, potash and soda; but the acids are considerably varied, so as to include hydrates, carbonates, sulphates, sulphites, hyposulphites, sulphovinates, oxalates, acetates and tartrates. Salts of almost every class of acids come thus to be represented, either in the present or former series of experiments on diffusion, while at the same time much information is elicited respecting the diffusive relation of the two important bases named.

Comparison of Salts of Potash and Soda.

Hydrate of Potash.—Time of diffusion 4·041 days. The usual number of eight cells of the 1 and 2 per cent. solutions of this substance were diffused, and four cells of the 4 and 8 per cent. solutions. The whole diffusates of each proportion were then mixed together, and the quantity of hydrate of potash diffused for two cells determined by an alkalimetric experiment, which was always repeated twice.

1. One per cent. of hydrate of potash, density 1·00978, diffused at 63°·4, gave 6·56 grs. of hydrate of potash for two cells.

2. 2·005 per cent. of hydrate of potash, density 1·01878, diffused at 63°·4, gave 12·88 grs. for two cells; calculated for 2 per cent., 12·84 grs. of hydrate of potash in two cells.

3. 4·01 per cent. of hydrate of potash, density 1·0366, diffused at 63°·4, gave 12·56 grs. for one cell; calculated for 4 per cent., 12·52 grs. of hydrate of potash in one cell.

4. 8·02 per cent. of hydrate of potash, density 1·07069, diffused at 63°·4, gave 26·20 grs. for one cell; calculated for 8 per cent., 26·12 grs. of hydrate of potash in one cell.

Diffusion of Hydrate of Potash in 4·04 days at 63°·4; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	6·56	1·022
From 2 per cent. solution . . .	12·84	2
From 4 per cent. solution . . .	25·04	3·900
From 8 per cent. solution . . .	52·24	8·137

Hydrate of Soda.—Time of diffusion 4·9497 days; the times chosen as hitherto for the corresponding potash and soda salts being always, when squared, in the proportion of 2 to 3. The usual number of eight cells of the 1 and 2 per cent. solutions were diffused, and four cells of the 4 and 8 per cent. solutions. The whole diffusates of each proportion were then mixed together, and the quantity of hydrate of soda diffused for two cells determined by alkalimetric experiments.

1. 1·043 per cent. of hydrate of soda, density 1·01256, diffused at 63°·3, gave 6·06 grs. for two cells; calculated for 1 per cent., 5·81 grs. of hydrate of soda in two cells.

2. 2·087 per cent. of hydrate of soda, density 1·0242, diffused at 63°·3, gave 11·58 grs. for two cells; calculated for 2 per cent., 11·09 grs. of hydrate of soda in two cells.

3. 4·177 per cent. of hydrate of soda, density 1·04666, diffused at 63°·3, gave 10·90 grs. for one cell; calculated for 4 per cent., 10·43 grs. of hydrate of soda in one cell.

4. 8·35 per cent. of hydrate of soda, density 1·08846, diffused at 63°·3, gave 21·10 grs. for one cell; calculated for 8 per cent., 20·22 grs. of hydrate of soda in one cell.

Diffusion of Hydrate of Soda in 4·95 days at 63°·3; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	5·81	1·048
From 2 per cent. solution . . .	11·09	2
From 4 per cent. solution . . .	20·86	3·765
From 8 per cent. solution . . .	40·44	7·30

The nearest approach to equality of diffusion in the hydrates of potash and soda, is exhibited by the 1 per cent. solutions, which are as 6·56 to 5·81, or as 100 to 88·57, being a difference of so much as 11·43 per cent.

Comparative Diffusion of Hydrate of Potash in 4·041 days at 63°·4, and of Hydrate of Soda in 4·95 days at 63°·3.

	From solutions of			
	1 per cent.	2 per cent.	4 per cent.	8 per cent.
Hydrate of potash	100	100	100	100
Hydrate of soda................	88·57	86·37	83·30	77·41

The marked departure from the usual ratio of diffusion, here exhibited, must not be overlooked in considering the relation between potash and soda salts.

Carbonate of Potash.—Time of diffusion 8·083 days, or double the time of hydrate of potash. The usual number of eight cells of the 1 and 2 per cent. solutions were diffused, with four cells of the 4 and 8 per cent. solutions, and the diffusates of each proportion determined by alkalimetric experiments as with the preceding alkaline hydrates.

1. 1·002 per cent. of carbonate of potash, density 1·00957, diffused at 63°·7, gave 6·15 grs. for two cells; calculated for 1 per cent., 6·13 grs. of carbonate of potash in two cells.

2. 2·005 per cent. of carbonate of potash, density 1·01843, diffused at 63°·7, gave 11·95 grs. for two cells; calculated for 2 per cent., 11·92 grs. of carbonate of potash in two cells.

3. 4·01 per cent. of carbonate of potash, density 1·03577, diffused at 63°·7, gave 11·48 grs. for one cell; calculated for 4 per cent., 11·44 grs. of carbonate of potash in one cell.

4. 8·02 per cent. of carbonate of potash, density 1·06935, diffused at 63°·7, gave 22·79 grs. for one cell; calculated for 8 per cent., 22·72 grs. of carbonate of potash in one cell.

5. 2·005 per cent. of carbonate of potash, density 1·01843, diffused at 68°·2, gave 12·64 grs. for two cells; calculated for 2 per cent., 12·62 grs. of carbonate of potash in two cells.

Diffusion of Carbonate of Potash in 8·08 days at 63°·7; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	6·13	1·028
From 2 per cent. solution . . .	11·92	2
From 4 per cent. solution . . .	22·88	3·839
From 8 per cent. solution . . .	45·44	7·624

Comparative Diffusion of Hydrate of Potash in 4·04 days at 63°·4, and Carbonate of Potash in 8·08 days at 63°·7.

	From solutions of			
	1 per cent.	2 per cent.	4 per cent.	8 per cent.
Hydrate of potash	100	100	100	100
Carbonate of potash	93·48	92·81	91·36	86·97

The diffusion of hydrate of potash appears to be excessive when compared with the carbonate of potash, as well as when compared with the hydrate of soda.

Carbonate of Soda.—Time of diffusion 9·8994 days. The usual number of eight cells of the 1 and 2 per cent. solutions of this substance were diffused, and four cells of the 4 and 8 per cent. solutions, and the diffusates determined by alkalimetric experiments.

1. 1·003 per cent. of carbonate of soda, density 1·01120, diffused at 63°·4, gave 6·04 grs. for two cells; calculated for 1 per cent., 6·02 grs. of carbonate of soda in two cells.

2. 2·007 per cent. of carbonate of soda, density 1·0216, diffused at 63°·4, gave 11·74 grs. for two cells; calculated for 2 per cent., 11·70 grs. of carbonate of soda in two cells.

3. 4·015 per cent. of carbonate of soda, density 1·04156, diffused at 63°·4, gave 10·74 grs. for one cell; calculated for 4 per cent., 10·71 grs. of carbonate of soda in one cell.

4. 8·03 per cent. of carbonate of soda, density 1·0800, diffused at 63°·4, gave 19·93 grs. for one cell; calculated for 8 per cent., 19·87 grs. of carbonate of soda in one cell.

In the two following additional experiments the diffusate was treated with hydrochloric acid, and estimated from the weight of chloride of sodium produced.

5. 2·007 per cent. of carbonate of soda, density 1·02166, diffused at 68°·1, gave 12·06 grs. for two cells; calculated for 2 per cent., 12·02 grs. of carbonate of soda in two cells at 68°·1.

6. 2·13 per cent. of carbonate of soda, density 1·02246, diffused at 59°·6 in eight cells, 11·12, 11·34, 11·17, 11·58; mean 11·38 grs. for two cells; calculated for 2 per cent., 10·65 grs. of carbonate of soda in two cells at 59°·6.

Diffusion of Carbonate of Soda in 9·9 days at 63°·4; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	6·02	1·028
From 2 per cent. solution . . .	11·70	2
From 4 per cent. solution . . .	21·42	3·661
From 8 per cent. solution . . .	39·74	6·792

The similarity of diffusion between the carbonates of potash and soda is remarkable in the 1 per cent. solution, which are as 6·13 to 6·02, or as 100 to 98·2; also in the 2 per cent. solutions, which were observed at two different temperatures.

Diffusion of 2 per cent. solutions of Carbonate of Potash in 8·083 days, and Carbonate of Soda in 9·9 days.

	Grs.	Ratio.
Carbonate of potash at 63°·7 . . .	11·92	100
Carbonate of soda at 63°·4	11·70	98·15
Carbonate of potash at 68°·2 . . .	12·62	100
Carbonate of soda at 68°·1	12·02	95·24

Comparative Diffusion of Carbonate of Potash in 8·083 days at 63°·7, and Carbonate of Soda in 9·9 days at 63°·4.

	From solutions of			
	1 per cent.	2 per cent.	4 per cent.	8 per cent.
Carbonate of potash	100	100	100	100
Carbonate of soda	98·20	98·15	93·63	87·44

The carbonate of soda appears to preserve more analogy to the hydrate of soda in its diffusion than the carbonate of potash to the hydrate of potash.

Comparative Diffusion of Hydrate of Soda in 4·937 days at 63°·3, and Carbonate of Soda in 9·9 days at 63°·4.

	From solutions of			
	1 per cent.	2 per cent.	4 per cent.	8 per cent.
Hydrate of soda	100	100	100	100
Carbonate of soda	103·62	105·50	102·68	98·27

Here we have a nearly equal diffusion with the times as 1 to 2 for the hydrate and carbonate of soda respectively.

Sulphate of Potash.—Time of diffusion 8·083 days. The solution of diffused salt was evaporated to dryness and weighed.

1. 1·005 per cent. of sulphate of potash, density 1·00844, diffused at 60°·3, in eight cells, 6·11, 6·21, 6·12, 6·32; mean 6·19 grs. in two cells; calculated for 1 per cent., 6·16 grs. of sulphate of potash in two cells.

2. 2·01 per cent. of sulphate of potash, density 1·01653, diffused at 60°·3, in eight cells, 11·61, 11·58, 11·50, 11·97; mean 11·66 grs. in two cells; calculated for 2 per cent., 11·60 grs. of sulphate of potash in two cells.

3. 4·02 per cent. of sulphate of potash, density 1·03240, diffused at 60°·3, in four cells, 10·80, 11·33, 11·20, 12·07; mean 11·35 grs. for one cell; calculated for 4 per cent. 11·35 grs. of sulphate of potash in one cell.

4. 8·04 per cent. of sulphate of potash, density 1·06306, diffused at 60°·3, in four cells, 21·91, 21·93, 22·00, 22·47; mean 22·08 grs. for one cell; calculated for 8 per cent., 21·96 grs. of sulphate of potash in one cell.

Diffusion of Sulphate of Potash in 8·083 days at 60°·3; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	6·16	1·062
From 2 per cent. solution . . .	11·60	2
From 4 per cent. solution . . .	22·70	3·914
From 8 per cent. solution . . .	43·92	75·72

The diffusion of sulphate of potash above, at 60°·3, appears to be similar to that of carbonate of potash at 63°·7, a higher temperature by 3°·4 (p. 413). The numbers for the sulphate of potash and hydrate of potash (p. 412) would probably correspond closely at the same temperature, the times of diffusion of the two substances being taken as 2 to 1.

Sulphate of Soda.—Time of diffusion 9·9 days. The diffusate was evaporated to dryness and weighed.

1. One per cent. of sulphate of soda, density 1·00940, diffused at 59°·9, in eight cells, 6·31, 6·47, 6·21, 6·32; mean 6·33 grs. for two cells.

2. 1·995 per cent. of sulphate of soda, density 1·01832, diffused at 59°·9, in eight cells, 12·02, 12·10, 11·66, 12·16; mean 11·98 grs. for two cells; calculated for 2 per cent., 12·00 grs. of sulphate of soda in two cells at 59°·9.

3. 3·99 per cent. of sulphate of soda, density 1·03594, diffused at 59°·9, in four cells, 10·00, 10·80, 11·53, 11·53; mean 10·96 grs. for one cell; calculated for 4 per cent., 10·98 grs. of sulphate of soda in one cell at 59°·9.

4. 7·98 per cent. of sulphate of soda, density 1·06960, diffused at 59°·9, in four cells, 20·50, 21·36, 20·01, 20·68; mean 20·64 grs. for one cell; calculated for 8 per cent., 20·69 grs. of sulphate of soda in one cell at 59°·9.

Diffusion of Sulphate of Soda in 9·9 days at 59°·9; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	6·33	1·055
From 2 per cent. solution . . .	12·00	2
From 4 per cent. solution . . .	21·96	3·66
From 8 per cent. solution . . .	41·38	6·896

The 2 per cent. solution of sulphate of soda above, at 59°·9, appears to be more diffusive than the corresponding solution of carbonate of soda at 59°·6, as 12·00 to 10·65 grs., or as 100 to 88·75.

The assumed relation in the times of equal diffusion for salts of potash and soda appears to derive support from the sulphates, particularly in the lower proportions of salt.

Comparative Diffusion of Sulphate of Potash in 8·083 days at 60°·3, and Sulphate of Soda in 9·9 days at 59°·9.

	From solutions of			
	1 per cent.	2 per cent.	4 per cent.	8 per cent.
Sulphate of potash............	100	100	100	100
Sulphate of soda	102·74	103·45	96·74	94·21

Another set of experiments made upon these two salts, simultaneously with certain oxalates and acetates which follow, may be placed here to illustrate the same relation. The preceding times of diffusion were observed.

5. 2·013 per cent. of sulphate of potash, diffused at 59°·8, in eight cells, gave 11·90, 11·94, 11·41, 11·71; mean 11·74 grs. for two cells; calculated for 2 per cent., 11·67 grs. of sulphate of potash in two cells.

6. Two per cent. of sulphate of soda, density 1·01846, diffused at 59°·6, in eight cells, gave 11·58, 11·56, 11·94, 11·97; mean 11·76 grs. of sulphate of soda in two cells.

The present results, from 2 per cent. solutions of these salts, are as follows:—

Sulphate of potash in 8·083 days at 59°·8 . . .	11·67	100
Sulphate of soda in 9·9 days at 59°·6	11·76	100·94

The diffusion in the selected times appears therefore to be, as nearly as possible, equal at the present temperatures.

Another experiment may be recorded at present, of which the object was to ascertain the influence of free sulphuric acid upon the diffusion of sulphate of soda.

7. Sulphate of soda, 2·02 per cent., to which an equivalent quantity of sulphuric acid was added, had the density 1·02703. This solution, diffused into pure water, in eight cells, at 59°·6, for the same time as the preceding sulphate of soda, gave a diffusate of 9·70, 10·06, 10·17 and 10·29 grs. of sulphate of soda; mean 10·05 grs. in two cells; calculated for 2 per cent., this diffusate becomes 9·95 grs. The presence of one equivalent of sulphuric acid appears therefore to diminish the diffusion of sulphate of soda considerably, namely, from 11·76 to 9·95 grs., or from 100 to 84·61. The free sulphuric acid diffused in the experiment was not determined.

Sulphite of Potash.—It was curious to observe how far this and other salts of the oxygen acids of sulphur correspond with the sulphates. Time of diffusion 8·083 days. The diffusate was treated with sulphuric acid and estimated in the form of neutral sulphate of potash.

1·90 per cent. of sulphite of potash, density 1·01753, diffused at 59°·5, in eight cells, gave 11·36, 10·72, 11·22 and 10·90 grs. in two cells; mean 11·05 grs. in two cells; calculated for 2 per cent., 11·63 grs.

Making the comparison for 2 per cent. solutions we have—

Sulphate of potash at 60°·3 . . .	11·60	100
Sulphite of potash at 59°·5 . . .	11·63	100·26

The two salts appear to have the same diffusibility.

Sulphite of Soda.—Time of diffusion 9·9 days. The diffusate was estimated in the same manner as the preceding salt.

2·26 per cent. of sulphite of soda, density 1·02330, diffused at 59°·6, in eight cells, gave 12·93, 13·35, 13·56 and 13·62 grs. in two cells; mean 13·37 grs. in two cells; calculated for 2 per cent., 11·83 grs.

The comparative diffusion of the sulphites of the two bases is as follows:—

Sulphite of potash in 8·083 days at 59°·5 . . .	11·63	100
Sulphite of soda in 9·9 days at 59°·6	11·83	100·72

The sulphites of potash and soda appear therefore to exhibit the usual relation of these two bases.

Hyposulphite of Potash.—Time of diffusion 8·083 days. The diffusate was evaporated to dryness with sulphuric acid, ignited and estimated from the sulphate produced.

1·925 per cent. of anhydrous hyposulphite of potash, density 1·0150, diffused at 59°·8, in eight cells, gave 11·66, 11·67, 12·01, 12·26 grs.; mean 11·90 grs. for two cells; calculated for 2 per cent., 12·37 grs. of hyposulphite of potash in two cells.

Comparing this salt with the sulphate of the same base, we have—

Sulphate of potash at 60°·3 . . .	11·60	100
Hyposulphite of potash at 59°·8 . .	12·37	106·44

A slight error in excess may possibly have been introduced from the circumstance that the hyposulphite of potash employed was not absolutely free from sulphate.

Hyposulphite of Soda.—Time of diffusion 9·9 days. The diffusate was estimated in the same manner as the preceding salt.

2·136 per cent. of anhydrous hyposulphite of soda, density 1·01778, diffused at 59°·9, in eight cells, gave 13·11, 12·77, 12·92, 11·99 grs.; mean 12·70 grs. for two cells; calculated for 2 per cent., 11·89 grs. of hyposulphite of soda in two cells.

The comparative diffusion of the salts of potash and soda appears thus:—

Hyposulphite of potash in 8·083 days at 59°·8 . . .	12·37	100
Hyposulphite of soda in 9·9 days at 59°·9	11·89	96·21

The relation of the sulphate and hyposulphite of soda appears still closer.

Sulphate of soda at 59°·6	11·76	100
Hyposulphite of soda at 59°·9 . .	11·89	101·10

Sulphovinate of Potash.—Time of diffusion 8·083 days. The diffusate was evaporated to dryness and ignited with sulphuric acid.

1·966 per cent. of sulphovinate of potash, of density 1·00977, diffused at 59°·8, in eight cells, gave 12·57, 12·48, 12·12 and 12·39 grs.; mean 12·39 grs. for two cells; calculated for 2 per cent., 12·60 grs. of sulphovinate of potash in two cells.

The diffusion of this salt appears in excess when compared with sulphate of potash.

Sulphate of potash at 60°·3 . . .	11·60	100
Sulphovinate of potash at 59°·8 . .	12·60	108·62

Sulphovinate of Soda.—Time of diffusion 9·9 days. The diffusate was estimated in the same manner as the preceding salt.

2·063 per cent. of sulphovinate of soda, of density 1·00944, diffused at 59°·6, in eight cells, gave 13·32, 13·50, 13·78 and 13·15 grs.; mean 13·44 grs. for two cells; calculated for 2 per cent., 13·03 grs. of sulphovinate of soda in two cells.

Comparing the two sulphovinates together, we have—

Sulphovinate of potash in 8·083 days at 59°·8 . . .	12·60	100
Sulphovinate of soda in 9·9 days at 59°·6	13·03	103·41

Neither of these sulphovinates appeared to suffer decomposition in the act of diffusion, at least to any considerable extent. But the experiments on both of these salts are less precise than usual, from the difficulty of obtaining them entirely free from sulphates.

Oxalate of Potash.—Time of diffusion 8·083 days. The diffusate was evaporated to dryness, ignited, and then converted into chloride of potassium.

1. 0·981 per cent. of anhydrous oxalate of potash, density 1·00775, diffused at 59°·8, in eight cells, 6·24, 6·22, 5·91, 5·97; mean 6·08 grs. for two cells; calculated for 1 per cent., 6·20 grs. of oxalate of potash in two cells.

2. 1·92 per cent. of oxalate of potash, density 1·01463, diffused at 59°·9, in eight cells, 11·54, 11·63, 11·94, 11·63; mean 11·68 grs. for two cells; calculated for 2 per cent., 12·17 grs. of oxalate of potash, in two cells.

3. 3·84 per cent. of oxalate of potash, density 1·02864, diffused at 59°·9, in four cells, 11·10, 11·16, 11·09, 10·92; mean 11·07 grs. for one cell; calculated for 4 per cent., 11·52 grs. of oxalate of potash in one cell.

4. 7·68 per cent. of oxalate of potash, density 1·05604, diffused at 59°·9, in four cells, 20·45, 20·63, 20·99, 20·15; mean 20·55 grs. for one cell; calculated for 8 per cent., 21·41 grs. of oxalate of potash in one cell.

Diffusion of Oxalate of Potash in 8·083 days at 59°·9; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	6·20	1·019
From 2 per cent. solution . . .	12·17	2
From 4 per cent. solution . . .	23·04	3·789
From 8 per cent. solution . . .	42·82	7·042

The oxalate of potash corresponds well with sulphate of potash.

Comparative diffusion in 8·083 days of Sulphate of Potash at 60°·3, and Oxalate of Potash at 59°·9.

	From solutions of			
	1 per cent.	2 per cent.	4 per cent.	8 per cent.
Sulphate of potash............	100	100	100	100
Oxalate of potash	100·65	104·91	101·50	97·47

The sensible excess in the diffusion of the 2 per cent. solution of oxalate of potash is, I believe, to be accounted for by this proportion having been estimated in the form of carbonate of potash instead of chloride of potassium.

Oxalate of Soda.—Time of diffusion 9·9 days. The diffusate was evaporated to dryness, ignited and then converted into chloride, as with the preceding oxalate of potash.

1. 0·925 per cent. of oxalate of soda, density 1·00882, diffused at 59°·9, in eight cells, 5·99, 5·81, 5·69, 5·59; mean 5·77 grs. for 2 cells; calculated for 1 per cent., 6·24 grs. of oxalate of soda in two cells.

It was found impossible to form a 2 per cent. solution of this salt from its sparing solubility, so that the observations respecting it are limited to the lowest proportion of salt.

The comparative diffusion from 1 per cent. solutions of these alkaline oxalates is as follows:—

Oxalate of potash in 8·083 days at 59°·9	6·20	100
Oxalate of soda in 9·9 days at 59°·9	6·24	100·65

Here again a nearly equal diffusion is observed in times of which the squares are as 2 to 3.

Acetate of Potash.—Time of diffusion 8·083 days. The diffusate was converted into chloride of potassium and weighed in that form.

1. 0·951 per cent. of anhydrous acetate of potash, density 1·00540, diffused at 60°·3, in eight cells, 6·01, 6·18, 6·27, 6·06; mean 6·13 grs. for two cells; calculated for 1 per cent., 6·44 grs. of acetate of potash in two cells.

2. 1·903 per cent. of acetate of potash, density 1·00976, diffused at 60°·3, in eight cells, 11·90, 11·91, 11·65, 12·24; mean 11·92 grs. for two cells; calculated for 2 per cent., 12·52 grs. of acetate of potash in two cells.

3. 3·807 per cent. of acetate of potash, density 1·01928, diffused at 60°·3, in four cells, 10·91, 11·08, 11·48, 11·18; mean 11·16 grs. for one cell; calculated for 4 per cent., 11·72 grs. of acetate of potash in one cell.

4. 7·614 per cent. of acetate of potash, density 1·03743, diffused at 60°·3, in four cells, 22·62, 21·72, 23·23, 22·42; mean 22·50 grs. for one cell; calculated for 8 per cent., 23·63 grs. of acetate of potash in one cell.

Diffusion of Acetate of Potash in 8·08 days at 60°·3; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	6·44	1·028
From 2 per cent. solution . . .	12·52	2
From 4 per cent. solution . . .	23·44	3·744
From 8 per cent. solution . . .	47·26	7·549

The acetate will be found to exceed sensibly the sulphate and oxalate of potash in diffusibility at the preceding temperature.

Comparative diffusion of Sulphate and Acetate of Potash in 8·083 days, at 60°·3.

	From solutions of			
	1 per cent.	2 per cent.	4 per cent.	8 per cent.
Sulphate of potash............	100	100	100	100
Acetate of potash	104·55	107·93	103·26	107·58

The acetate of potash appears to possess that increased diffusibility which is observed in bicarbonate of potash. But a parallelism still holds between the acetate and sulphate, and the diffusion of the two salts would probably coincide if that of the acetate were observed at a temperature 3° or 4° lower than the sulphate.

Acetate of Soda.—Time of diffusion 9·9 days. The diffusate was converted into chloride of sodium and weighed in that form.

1. 0·958 per cent. of anhydrous acetate of soda, density 1·00530, diffused at 59°·6, in eight cells, 6·33, 6·56, 6·63, 6·05; mean 6·39 grs. for two cells; calculated for 1 per cent., 6·67 grs. of acetate of soda in two cells.

2. 1·917 per cent. of acetate of soda, density 1·01032, diffused at 59°·6, in eight cells, 11·70, 12·04, 11·90, 12·19; mean 11·96 grs. for two cells; calculated for 2 per cent., 12·46 grs. of acetate of soda in two cells.

3. 3·835 per cent. of acetate of soda, density 1·02039, diffused at 59°·6, in four cells, 12·19, 11·74, 12·15, 11·93; mean 12·00 grs. for one cell; calculated for 4 per cent., 12·52 grs. of acetate of soda in one cell.

4. 7·67 per cent. of acetate of soda, density 1·03968, diffused at 59°·6, in four cells, 23·49, 22·26, 23·87, 22·49; mean 23·03 grs. for one cell; calculated for 8 per cent., 24·02 grs. of acetate of soda in one cell at 59°·9

Diffusion of Acetate of Soda in 9·9 days at 59°·6; two cells.

	Grs.	Ratio.
From 1 per cent. solution . . .	6·67	1·070
From 2 per cent. solution . . .	12·46	2
From 4 per cent. solution . . .	25·04	4·019
From 8 per cent. solution . . .	48·04	7·711

The diffusion of acetate of soda presents a general parallelism to that of acetate of potash for the times chosen, the temperatures of the two series of experiments differing only 0°·7.

Comparative diffusion of Acetate of Potash in 8·083 days at 60°·3, and Acetate of Soda in 9·9 days at 59°·6.

	From solutions of			
	1 per cent.	2 per cent.	4 per cent.	8 per cent.
Acetate of potash	100	100	100	100
Acetate of soda	103·57	99·52	106·82	101·65

Tartrate of Potash.—Time of diffusion 8·08 days. The diffusate was evaporated to dryness, ignited, and then converted into chloride of potassium.

1·82 per cent. of anhydrous tartrate of potash, density 1·01227, diffused at 59°·9, in eight cells, 9·96, 10·02, 10·06, 9·87; mean 9·98 grs. for two cells; calculated for 2 per cent., 10·96 grs. of tartrate of potash in two cells.

Tartrate of Soda.—Time of diffusion 9·9 days. The diffusate was evaporated to dryness, ignited, and then converted into chloride of sodium.

2·03 per cent. of anhydrous tartrate of soda, density 1·01460, diffused at 59°·6, in eight cells, 10·84, 10·77, 10·81, 10·82; mean 10·81 grs. for two cells; calculated for 2 per cent., 10·65 grs. of tartrate of soda in two cells.

Diffusion of 2 per cent. solutions of Tartrate of Potash in 8·08 days at 59°·9, and Tartrate of Soda in 9·9 days at 59°·6.

Tartrate of potash	10·96	100
Tartrate of soda	10·65	97·18

The tartrate of soda happens to correspond absolutely with the carbonate of soda, the diffusate of the latter salt obtained at the same temperature being also 10·65 grs. (p. 486).

The double *Tartrate of Potash and Soda* afforded an interesting instance of decomposition produced by diffusion. Instead of the usual diffusion cells, a single plain cylindrical jar was employed about 5 inches in diameter and 10 inches in height. A portion of a 4 per cent. solution of Rochelle salt, amounting to 5000 grs. of liquid, was covered over by nine times as much pure water, in this jar, and the salt allowed to diffuse upwards for three weeks at 56°. The upper third of the fluid column, amounting to 17,000 grs. of liquid, was then drawn off, evaporated to dryness, and the salt ignited and converted, by the addition of hydrochloric acid, into chloride, which weighed 3·14 grs. The salt proved to be a mixture of the two chlorides in the proportion of 2·43 grs. of chloride of potassium and 0·71 gr. of chloride of sodium. This gives the following as the composition of the diffusate:

Tartrate of potash	3·68
Tartrate of soda	1·17
	4·85

It hence follows that the proportion of potash, or of tartrate of potash, in the diffusate is nearly three times greater than existed in the original Rochelle salt. It will be recollected that the salt decomposed is, strictly speaking, a bibasic tartrate of potash and soda, and not a double tartrate of potash and soda. The diffusate was observed to be exactly neutral to test-paper. This mode of diffusing upwards in water from the lower part of a deep jar obviously gives the greatest degree of separation attainable in consequence of unequal diffusibility.

I may confine myself at present to the conclusion that of the nine pairs of potash and soda salts, of which the diffusion is compared in this paper, the potash salt uniformly exceeds in diffusibility the corresponding soda salt; that the ratio between the two classes is always sensibly the same, or exhibits only a small range of variation at the temperature of the experiments, which was near 60°; with the peculiar exception of the hydrates of potash and soda.

XXI. *The Figure and Primitive Formation of the Earth, or Researches in Terrestrial Physics.*—Part I. *By* Henry Hennessy, *M.R.I.A. &c. Communicated by Major* Ludlow Beamish, *F.R.S.*

Received October 29,—Read December 17, 1846.

1. THE hypothesis by which the figures of the heavenly bodies are theoretically explained has long engaged the attention of geologists and geometers, without having acquired any important improvements. Great as have been the discoveries which have originated from this hypothesis, it remains in nearly the same philosophical position as that to which it had arrived when Clairaut published his Theory of the Figure of the Earth. During the period of more than a century which has elapsed since the appearance of that immortal work, the improvements which have been made in the theory of the figures of the planets, appear to consist chiefly in discoveries connected with the attractions of bodies, and in some important generalizations of the equilibrium and motions of fluids.

Comparatively few positive discoveries have however been as yet made in geology as deductions from the hypothesis of the primitive fluidity of the earth. In explanation of this circumstance several causes may be assigned, one of which appears to be the limited nature of the hypothesis. It has not been considered sufficient to suppose that the earth was originally a mass of heterogeneous matter in a fluid state; an additional supposition has been made, in support of which I am not aware that any evidence has been ever adduced. The supposition alluded to is, that the volume of the entire mass and the law of density of the fluid have not been changed by the solidification of a part of that fluid, no matter how far the solidification may have proceeded; or in other words, that the distribution of the molecules composing the earth is the same in the present state of our planet as that which they had when the mass was fluid. Although no precise evidence can be brought forward for the examination of this portion of the hypothesis, it appears not to be entirely consistent with what is known respecting the solidification of fluids. It is thus defective from appearing to involve an unproved and improbable physical law. Its exclusion from the hypothesis will make the latter more general and more applicable to the explanation of certain cosmical phenomena. Making the simplified hypothesis the basis of my investigations, it shall be their object further to generalize the theory of the figure of the earth, and to examine the nature and the energy of the physical and mechanical actions which may have been exerted upon its surface during its different geological transformations.

2. Let the earth be considered to have been originally a heterogeneous fluid mass, possessing only such general properties as those which have been established for fluids. Let x, y, z be the rectangular coordinates of μ, an elementary molecule of the fluid; and let the components of the forces, parallel respectively to the axes of x, y, z, be X, Y, Z, if the mass were not in rotation but at rest and in equilibrium. Let the mass rotate about the axis of z with an angular velocity at unity of distance represented by α, let the density at μ be represented by ϱ, a function of x, y, z; and let p represent the entire pressure upon μ, then*

$$dp=\varrho(\mathrm{X}dx+\mathrm{Y}dy+\mathrm{Z}dz)+\alpha^2(xdx+ydy).$$

The equation of the exterior surface of the fluid, and of the surfaces of equilibrium in its interior, will be

$$\mathrm{X}dx+\mathrm{Y}dy+\mathrm{Z}dz+\alpha^2(xdx+ydy)=0.$$

Let M represent the sum of the moments by which the rotation of the fluid mass was at first produced, and let the axis of z pass through the centre of gravity, then†

$$\alpha=\frac{\mathrm{M}}{\Sigma\mu(x^2+y^2)}.$$

The numerator at the right side of the above equation is evidently constant, and the denominator is a quantity depending upon the distribution of the molecules of the fluid about the centre of gravity of the entire mass. Let I represent the value of $\Sigma\mu(x^2+y^2)$ when α was the angular velocity of rotation of the body, and let I$'$ be its value corresponding to an angular velocity of rotation denoted by α'. If α should not be known independently, but if I, I$'$ and α' be known, then the equation to the free surface of the fluid can be transformed into

$$\mathrm{X}dx+\mathrm{Y}dy+\mathrm{Z}dz+\frac{\alpha'^2\mathrm{I}'^2}{\mathrm{I}^2}(xdx+ydy)=0. \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1.)$$

In any solutions heretofore given of the problem of the determination of the figure of the earth, the coefficient $\frac{\mathrm{I}'^2}{\mathrm{I}^2}$ seems not to have been noticed from the nature of the assumption which has been mentioned in (Art. 1.).

When X, Y, Z are the components produced by the mutual attractions of the molecules of the fluid according to a certain function of x, y, z, then the values of X, Y, Z will in general depend upon the form of the entire mass and of its surfaces of equilibrium, and again that form will depend upon the values of the components and of α'. As the value of I depends upon the form of the mass, it must also depend upon X, Y, Z; but it may be considered independently if the conditions upon which any particular solution of equation (1.) is to be made are such as to assign what function it may be of the coordinates. Considered under this point of view, the three first terms, and the fourth or last term at the left side of the equation (1.), may be considered as independent quantities whose values maybe found separately, and $\frac{\mathrm{I}'^2}{\mathrm{I}^2}$ may be regarded as a coefficient affecting α'^2 of such a nature as to satisfy the equation

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* Poisson, Mécanique, tom. ii. p. 536, 2$^{\text{ieme}}$ edit.

† Ibid. p. 79.

$$\alpha = \alpha' \frac{I'}{I} \qquad (2.)$$

3. In order to arrive at a solution of the problem of the figure of the earth, it has been found necessary to suppose that the primitive fluid mass deviated but little from the spherical form. If the spheroid be in rotation, it must follow that its axis of rotation should be that one of all the axes passing through the centre of gravity, with respect to which the sum of the forces acting upon the system would be a maximum. This axis may therefore be supposed to coincide very nearly with the position of the present axis. If no other forces be supposed to act upon the mass but the mutual attractions of its molecules and centrifugal force, then equation (1.) will rigorously represent the general equation of its surface, and the consideration of its physical or mechanical changes could be treated with less difficulty.

Whatever may be the cause of the primitive fluidity of the earth, and whatever may be the nature of the process of solidification by which at least a portion of it has arrived at a solid state, if that process should be such that a shell would be first formed surrounding a nucleus of matter in a state of fluidity, and if solidification be accompanied by a change in density of the matter solidified, it appears that some change would be produced in the motions of the entire mass about its axis, and in the arrangement and composition of that portion of the fluid constituting the nucleus. The manner in which, from physical or chemical causes, the solidifying process may proceed, will to a great extent determine what may be the actions mutually exercised by the nucleus and shell. The combination of such actions, with the changes which may have occurred in the velocity of rotation of the mass, will be thus known, and their influence upon the geological phenomena occurring during the different epochs of the physical history of the earth can be thus appreciated. In this way it may be possible to carry our ideas back to the remoter periods of the earth's existence, and to assist in explaining the phenomena which geological observers are constantly unfolding.

The application of physical and mechanical science to questions connected with geology, has been made only within a comparatively recent period, and the subject seems yet to require a more complete systematizing in order to bring it into the class of sciences which belong properly to what may be called the mechanics of the universe. An important step towards connecting geology with physical astronomy has already been made by Mr. Hopkins in his researches concerning the constitution and thickness of the present solid shell of the globe. One of the objects of the present memoir will be fulfilled if it should in any way tend to increase that connexion.

4. Adopting in its greatest generality the hypothesis that the earth was originally a fluid mass in rotation, the particles of which attracted each other with forces varying inversely as the squares of their distances, and that the figure of the mass was nearly spherical, it will be impossible to proceed with the general investigation of the

figure which the forces acting on its different parts would ultimately produce without any knowledge of the peculiar physical nature of the fluid. It appears to be sufficiently demonstrated, that the figure which such a fluid mass would assume in virtue of the mutual attractions of its particles and of centrifugal force would be an ellipsoid of revolution. It is superfluous therefore to enter upon that portion of the subject. Assuming then the figure of the mass to be an ellipsoid of revolution, I shall endeavour to obtain general expressions for its ellipticity, and for the variation of gravity at its surface.

From what has been stated in the last paragraph of art. 2, it appears to be unnecessary to transform equation (1.) into the equation of a similar form which the conditions of the present problem would require, and from this cause the whole investigation may be considerably abridged.

Let the origin of the coordinates be at the centre of gravity of the fluid mass, let r represent the radius vector drawn from this origin to any point in any surface of equilibrium of the fluid, let θ represent the angle formed between this radius and the axis of z or axis of rotation, let ω represent the angle formed by the plane which passes through the radius r and the axis of rotation with the plane of zx, then

$$z=r\cos\theta,\quad x=r\sin\theta\cos\omega,\quad y=r\sin\theta\sin\omega.$$

Let J represent in this case the fourth term at the left side of the integral of (1.), and let f represent the centrifugal force of a point situated at distance unity from the axis, hence

$$\mathrm{J}=\frac{1}{2}f(x^2+y^2)=\frac{1}{3}fr^2-\frac{1}{2}fr^2\left(\cos^2\theta-\frac{1}{3}\right).$$

If it be assumed that the polar and equatorial axes of the spheroid always differ but very little, we shall have for the determination at any period of f_1 the centrifugal force at the equator,

$$f_1=f'\frac{a_1\mathrm{I}'^2}{a'\mathrm{I}^2}, \quad \ldots\ldots\ldots\ldots\ldots \quad (3.)$$

where a_1 represents the semipolar axis at that period, and a' the same semiaxis at present, f' being the centrifugal force at the equator at present. Let ϱ represent the density at any point of a surface of equilibrium, the polar radius of which is a, and the ellipticity e, then as the figures of the mass and of its surfaces of equilibrium differ so little from the spherical form, r may be supposed nearly equal to a, and hence for the determination of e we shall have the equation*

$$\mathrm{U}^{(i)}\left\{\frac{4}{5}\pi a^5\int\varrho de-\frac{4}{3}\pi a^2e\int\varrho d.a^3+\frac{4}{3}\pi\int\varrho d(a^5e)\right\}-\frac{fa^5}{2\beta}\left(\mu^2-\frac{1}{3}\right)=0\,;$$

where $\mathrm{U}^{(i)}$ is a function of the coordinates, βa constant, and $\mu=\cos\theta$. If E represent the ellipticity, and ϱ' the density at the exterior surface, it follows that

$$\mathrm{E}=\frac{f_1\mathrm{E}}{\frac{8}{5}\pi(5\mathrm{E}\int\varrho a^2da+\int a^5\mathrm{E}d\varrho-\mathrm{E}\varrho')}. \quad \ldots\ldots\ldots\ldots \quad (4.)$$

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* Mécanique Céleste, tom. ii. p. 88.

If m' represent the ratio of centrifugal force f' to gravity g' at the equator, then

$$f_1 = \frac{m'g'a_1 I'^2}{a' I^2}.$$

If this value of f_1 be substituted in (4.), and if all the integrations be performed according to the given value of the function ϱ, an equation may be obtained after due reduction of the form

$$E = \frac{a_1 m' g' I'^2}{a'} \varphi(a), \quad \ldots\ldots\ldots\ldots \quad (5.)$$

in which equation I is considered as a function of a, and where φ is a functional symbol. That I may be considered as a function of a, is evident from the transformation of x, y, z into polar coordinates, and from the assumed identity of r and a. The above equation appears therefore to be general, or applicable to the consideration of the figure of any fluid mass upon the conditions which have formed the groundwork for its investigation.

In applying equation (5.) to the case of the earth's ellipticity, the values of m', g', a' and I', known at the present day, may be introduced. If it be supposed that the present ellipticity of the earth is the same as that which it had at the time when the first external coat of the shell had solidified from the fluid, I' will be a function of E, which can be then found if I' should be introduced under such a form by some further transformations.

The quantities I and I' are evidently the moments of inertia of the mass with respect to the axis of z during certain states of the arrangement of its molecules about the centre of gravity. Hence from the properties of ellipsoids of revolution

$$I' = \frac{2M_1 a'^2}{5\sigma},$$

σ being a number depending upon the arrangement of the particles in the interior of the mass, M_1 representing the earth's mass, and a' the present polar radius of the earth, which, without sensible error, may be used for the equatorial radius. From the consideration of the phenomena of precession and nutation, the following expression for σ' has been obtained*—

$$\sigma = \frac{P}{E - \frac{1}{2}m'},$$

where P represents a number deduced from the phenomena alluded to. If the above values of I' and σ be substituted in (5.), it will be transformed into

$$E = mQ \frac{\left(E - \frac{1}{2}m'\right)^2}{P^2},$$

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* Pontécoulant, Théorie Analytique du Système du Monde, tome ii. p. 475.

where Q is used for brevity instead of

$$\frac{4}{25}a_1 g' \mathrm{M}_1^2 a'^3 \varphi(a).$$

The above expression gives

$$\mathrm{E}=\frac{1}{2m\mathrm{Q}}\left\{m^2\mathrm{Q}+\mathrm{P}^2+p\sqrt{2m^2\mathrm{Q}+\mathrm{P}^2}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

If from any cause, E_1, the present ellipticity of the earth, should not be identical with E, and that we should wish to obtain the latter, the numerical value of σ, calculated from the formula

$$\sigma=\mathrm{P}\left(\mathrm{E}_1-\frac{1}{2}m\right)^{-1},$$

must be introduced in the value of I′ and thence in equation (5.).

5. The variation of gravity at the surface of the spheroid, during its fluid state and during the process of its solidification, may now be considered, the mass being supposed in both cases to consist of spheroidal shells having a density increasing from the external surface to the centre.

From the supposition which has been just made, if γ represent the entire force of gravity at the surface of the spheroid, we shall have

$$\gamma=\frac{4\pi}{3r^2}\cdot\int\varrho d.a^3+\frac{4\beta\pi}{r^2}\int\varrho d.\left(a^3\mathrm{Y}_0+\frac{3a^5}{5r^2}\mathrm{Y}_2\right)-\mathrm{J},$$

Y_0 and Y_2 being rational functions of the coordinates; and let it be remembered that at the surface

$$r=a_1[1+\beta(\mathrm{Y}_0+\mathrm{Y}_2)],$$

and that

$$\frac{4\beta\pi}{5}\int\varrho.d.a^5\mathrm{Y}_2=\frac{4\beta\pi}{3}\mathrm{Y}_2\int\varrho.da^3+\frac{1}{2}f\left(\cos^2\theta-\frac{1}{3}\right).$$

Let for brevity

$$\mathrm{G}=\frac{4\pi}{a_1^2}\int\varrho a^2da-\frac{8\beta\pi\mathrm{Y}_0}{a_1^2}\int\varrho a^2da+\frac{4\beta\pi}{a_1^2}\int\varrho da^3\mathrm{Y}_0-\frac{2}{3}f.$$

Let G′ represent the attraction at the surface of the earth at present, then if all quantities of the order β^2 and $\beta f d_1$ be neglected, we shall have after a few reductions,

$$\gamma=\mathrm{G}+\left(\frac{5}{2}m\mathrm{G}'\frac{\mathrm{I}'^2a_1}{\mathrm{I}^2a'}-\mathrm{EG}\right)\left(\cos^2\theta-\frac{1}{3}\right);$$

$m'\mathrm{G}'\frac{\mathrm{I}'^2a_1}{\mathrm{I}^2a'}$, the value of f, being here substituted for it.

If after the solidification of the external portion of the fluid into a spheroidal shell the axes of the shell undergo no great changes in magnitude, then whatever may be the physical changes occurring within the exterior surface of the shell, it will follow, from the little difference between the figure of the mass and that of a sphere, that the value of G will be invariable. Hence we may make $G'=G$, and $a_1=a'$, therefore

$$\gamma=G'\left[1+\left(\frac{5}{2}m'\frac{I'^2}{I_1^2}-E\right)\left(\cos^2\theta-\frac{1}{3}\right)\right];$$

I_1 representing the value of $\Sigma\mu\,(x^2+y^2)$ at any time after the formation of the shell. Let

$$\Gamma=G'-\frac{1}{3}G'\left(\frac{5}{2}m'\frac{I'^2}{I_1^2}-E\right);$$

then neglecting all powers of the ellipticity higher than the first,

$$\gamma=\Gamma\left[1+\left(\frac{5}{2}m'\frac{I'^2}{I_1^2}-E\right)\cos^2\theta\right]. \quad \text{. . . . .} \quad (7.)$$

If $\theta=90°$, then $\gamma=\Gamma$, so that Γ will be the expression for gravity at the equator. The expression for Γ_1, gravity at the poles, will be

$$\Gamma_1=\Gamma\left[1+\left(\frac{5}{2}m'\frac{I'^2}{I_2^1}-E\right)\right].$$

Hence if we designate by S the excess of gravity at the pole above gravity at the equator divided by the latter quantity, we shall have the general theorem

$$S+E=\frac{5}{2}m'\frac{I'^2}{I_1^2}. \quad \text{. . . . .} \quad (8.)$$

If $I'=I_1$, this expression will be identical with what is generally called CLAIRAUT's theorem.

If the earth had been originally a homogeneous fluid mass, and if in solidifying it continued so, then $E=\frac{5}{4}m'$, $S=E$.

If the spheroid were heterogeneous, the excess of gravity at the pole above gravity at the equator at any period of time divided by the latter quantity, and the excess of the equatorial axis above the polar axis divided by the latter axis, would form two fractions, the sum of which multiplied by the square of the ratio of the moment of inertia of the mass at the same period to its present moment of inertia, would form a constant product which would be equal to twice the ellipticity which the spheroid would have in the case of homogeneity.

This and the foregoing article appear to contain all that it may be at present possible to deduce from the improved hypothesis of the primitive state of the earth, with relation to its figure, and to the variation of gravity at its surface. It may be hereafter possible to assign to the quantities entering $\phi(a)$ in equation (5.) such values deduced from considering the physical properties of the primitive fluid, as would enable us to find a numerical value for the ellipticity.

6. In art. 3, a short general sketch has been given of the consequences which may result from the improved hypothesis of the primitive fluidity of the earth to physical geology, or to the changes occurring upon the external crust of the earth during

the process of its solidification. It is now proposed to commence the investigation of these geological consequences.

Before proceeding to the purely mathematical portions of this investigation, it seems necessary that some preliminary remarks should be made on the nature of the solidification of the globe. It seems the more necessary that these remarks should be now given, as they will not probably be found to agree entirely with those which have been made on the same subject by an eminent geologist and geometer*. It is, however, satisfactory to reflect that even if my views respecting the solidification of the earth should be more correct than those of Mr. Hopkins, the real value of that gentleman's researches will still remain unaltered.

Although until now no allusion has been made to the probable cause of the primitive fluidity of the earth, it becomes necessary in order to proceed with the geological portion of these investigations that this cause should be assigned. Intense heat is that which is generally supposed to be the cause, and which the advocates of the earth's central heat seem to support by numerous facts. The solidification of this heated mass of fluid is so connected with its refrigeration, that some remarks on the latter subject must accompany or precede any investigations about the former.

If the whole earth from the action of a high temperature were reduced to that state of fluidity which forms the groundwork of the hypothesis upon which the theory of its figure is founded, it appears probable that the fluid mass would be extremely heterogeneous chemically, as well as mechanically. New chemical combinations would be formed, of whose physical properties it would be difficult to form an accurate idea. After the most energetic combining tendencies of the different substances composing the fluid would have been satisfied, the mass may be supposed to have arrived at a state of comparative chemical stability. Such properties of the different compounds as density and compressibility, would then exert a direct influence upon the nature of their arrangement around the centre of gravity of the spheroid. Every portion of the fluid, denser than the stratum, in which from any cause it may happen to be, would sink until it would meet a stratum of equal density. The light portions of the fluid which may happen to be in heavier strata than themselves, would on the contrary ascend until equilibrium would be obtained. The fluid mass would thus arrive at length at such a state, that it would consist of a series of spheroidal strata, each of uniform density throughout its own mass, and having that density expressible as a function of its axes.

At some time after the arrival of the fluid at this state, and perhaps before it, portions of its heat would radiate in space. The exterior portions of the fluid would cool first, until they would acquire, according to the particular circumstances which may influence their cooling, certain densities. If the effect of refrigeration be in general an increase in density of the matter cooled, then the cooled portions of the fluid will sink. The higher temperature of the matter yet unexposed to cooling influences, would then tend to change the acquired densities of the cooled matter. The as yet uncooled fluid would have its temperature reduced from contact with the cold particles from above, and it would tend to change its position in a similar manner to the portions at first cooled. As each cooled portion of the fluid descends, the three following causes would therefore impede its descent.

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* Hopkins, Philosophical Transactions, 1839.

1. From the arrangement already indicated of the denser strata about the centre of the mass, and from the nature of the law of density of the strata, each stratum into which the cooled fluid would descend, would be denser than the preceding.

2. If the general effect of the refrigeration be to increase the density of the cooled matter, each stratum would have its density augmented by the passage through it of the cooler matter from above.

3. The descending portions will have their densities diminished by the increase in their temperature.

During this process of circulation the interior matter in a state of fusion will be losing some of its heat by conduction. It must be evident however that if the temperature of the fluid be very high, the cooling would be carried on at first chiefly by the process of circulation. If, as analogy seems to point out, the conducting power of the fluid were small, the process of circulation would long continue to perform a principal part in the refrigeration of the fluid.

Although from the imperfect state of our knowledge with respect to the cooling of fluids it would be impossible to arrive at the precise laws and nature of the process of circulation, it yet seems probable from the three impeding causes which have been adduced, that the energy of this process would diminish from the surface of the spheroid to its centre. *The principal oscillations of the fluid produced by this cause would therefore be at first confined to the vicinity of the surface.* A solid crust may therefore be formed at the surface, long before the process of circulation could have extended to any great depths. We should thus have an external solid crust with strata of the imperfect fluid which may have been subjected to the process of circulation below it, and in the centre a mass of matter still retaining a high state of fluidity. The existence at the centre of the spheroid of a solid nucleus of small mass compared to the entire mass of the earth, cannot, as will hereafter appear, exercise any important influence on geological phenomena. If from compression, or any other cause, this solid nucleus should exist, it is evident that solidification would proceed much more slowly upon it upwards, than upon the interior surface of the shell downwards; or in other words, the increase of its mass after its first formation would be small compared to the increase of the mass of the shell subsequent to its first solidification. Whether such an internal solid nucleus exists or not, certain phenomena will attend the formation of the shell which it may be important to remark. From what is known respecting the solidification of fused substances, it may be inferred that at the moment when a portion of the fluid assumes the solid state a considerable quantity of latent heat will be eliminated. A portion of this heat will pass upwards through the shell, and another portion will pass into the imperfect fluid immediately below, tending to bring it back to a state of more perfect fluidity. If the quantity of latent heat thus eliminated should be great, it may exert an influence in changing the arrangement of the parts of the shell which it may be hereafter useful to consider. The effect of the elimination of latent heat upon the process of circulation would be evidently such as to render that process still more complex than what it was before, and its examination would thus be attended with still more difficulty and uncertainty. A very accurate examination of this portion of the phenomena attending the earth's refrigeration, appears not to be necessary for the present, and it will be found most convenient to defer its consideration, if it should be required in any future portion of these researches.

7. The motions of the shell and internal fluid matter, and their mutual actions depend so much upon the arrangement of the molecules of the primitive fluid mass, that it would be desirable before attempting their investigation to form if possible a few precise ideas respecting the last mentioned subject. The results which may be thus obtained with respect to the dimensions and law of density of the primitive fluid, will also enable us to find the probable values for $\varphi(a)$, or Q, which should be substituted in this case respectively in either equations (5.) or (6.), in order to obtain the ellipticity of the spheroid.

Let the mass be supposed to have arrived at the state alluded to in the foregoing article, when "it would consist of a series of spheroidal strata, each of uniform density throughout its own mass, and having that density expressible as a function of its axes." Each stratum would have to sustain the normal pressures of all the strata above it, whether these pressures be produced by the action of gravity or other causes. The compressive force exercised by the upper strata upon those farther from the surface, would tend to increase the density of the latter. How far this increase of density from compression may proceed without solidification, we have no precise experimental evidence by which to judge. The celebrated experiments of Sir James Hall appear, however, to show that from the action of a great compressive force, matter in a fused state may very nearly retain the volume, and therefore the specific gravity which it had when solid. If from the combined action of increased pressure and increased temperature the specific gravity of the matter should be augmented, while its fluidity should be retained, it would fulfil the conditions of the hypothesis made in explanation of the earth's figure. If it can be assumed that the substances composing those portions of the globe inaccessible to observers are similar in constitution to those which are found at the surface, this portion of the subject appears to be susceptible of experimental examination. Until such an examination shall have been made, the mass may be supposed to have an arrangement such as that indicated in art. 6. If a solid nucleus of comparatively small mass should be formed, the densities of its strata may be supposed such, as to be expressible according to the same function of their axes as the densities of the fluid strata.

Let the fluid mass be conceived to consist of an infinite number of pyramids or columns meeting at its centre. Let, in conformity with the supposition mentioned by LAPLACE, the relation between the pressure Π at any point in one of these fluid columns, and the density ϱ be expressed by the equation*

$$\frac{d\Pi}{d\rho}=2k\varrho,$$

$2k$ being a constant depending on the peculiar physical properties of the fluid. The value of ϱ deduced from this equation, may after a few reductions be expressed under the form

$$\varrho=\frac{\mathrm{A}}{a}\sin an;$$

where a is the semipolar axis of the spheroidal stratum in which the point may be, A a constant, and n a constant depending on the constitution of the fluid, for n is here used to express $\sqrt{\frac{2\pi}{k}}$.

Let M_1, as before, represent the mass of the spheroid which is supposed to remain constant, let ϱ' represent its density at the surface when fluid, and let D represent its mean density, so that we shall have very nearly

$$\mathrm{D}=\frac{3\mathrm{M}_1}{4\pi a_1^3},$$

a_1 representing the semipolar axis of the fluid mass, and π, as in every other part of this memoir, representing the ratio of the diameter of a circle to its circumference. Let c represent the amount of compression of the fluid produced by the pressure of a column l units in height, and the ratio of which to the earth's radius is represented by m_1. Then the values of n and a_1 can be determined from the equations

$$\frac{na_1}{\tan na_1}=1-\frac{c}{m}; \quad \frac{\mathrm{D}}{\varrho'}=\frac{3c}{mn^2a_1^2}.$$

Remembering the value of D, and that $m_1=\frac{l}{a_1}$, we can obtain from the second of the above equations,

$$a_1=\frac{n}{2}\sqrt{\frac{\mathrm{M}_1 l}{c\pi\varrho'}}. \quad \ldots\ldots \quad (9.)$$

Let for brevity the quantity under the radical be called h^2. Then for the determination of n, we shall have the equation

$$1-\frac{cnh}{2l}-\frac{n^2h}{2\tan\frac{1}{2}n^2h}=0. \quad \ldots\ldots \quad (10.)$$

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* Méc. Cél., tome v. p. 49.

The value of n found from this expression by successive approximations, may be substituted in (9.), whence the value of a_1 can be obtained.

By means of the operations above indicated, if sufficient data existed, some knowledge could be obtained of the arrangement of the molecules of the primitive fluid about their centre of gravity. At present no experimental data appear to exist by which numerical values could be assigned to c or l. The experiments of MM. COLLADON and STURM show that the compressibilities of different liquids vary considerably, according to their physical properties. It would be impossible therefore, from analogy with their experiments, or those of M. ŒRSTED, to form any accurate idea of the compressibility of the fluid constituting the earth when in its supposed state of fusion. The calculation of a precise value for n or a_1 seems then to be at present impossible, but geological considerations appear to impose certain limits on the value which a_1 may have had. The value of a_1 may have been equal to, or greater or less than the present semipolar axis of the earth. If it were greater, the difference should be small compared to its whole length; for if this difference were great, the external shell first formed should (no matter from what cause) arrive at its present dimensions, and in doing so it would have to undergo immense contortions of whose existence no evidence can be adduced. If a surface be conceived to pass through the centres of gravity of the infinite number of pyramidal segments into which we may conceive the shell to be divided, it is evident that all of these segments could not descend below that surface, or could not all approach in the same degree towards the centre of the mass. The shell should be broken in many places to permit the displacement of the segments, as the amount of common displacement from the contraction of the shell by refrigeration would not effect the reduction of its dimensions to those which it has at present. The irregularities of the surface of the fractured shell would evidently be in proportion to its primitive axes.

If a_1 were less than the present semipolar axis of the earth, then in order that the external coat of the shell first formed should arrive at its present dimensions, it should receive additions in some parts. If the difference between a_1 and the present semipolar axis should have been great, the effect of the contraction of the shell from refrigeration may, as in the foregoing paragraph, be neglected. From some cause, no matter what, the earth's mass should expand, and in the expansion rents would be produced in the shell. These empty spaces may be afterwards filled up with injected matter pushed forward by further expansion during the subsequent formation of the under strata of the shell. The entire shell formed of the cemented portions of the first solidified mass, and the new coats of matter added from within, may be again ruptured, and a process similar to the first may be again repeated. As the whole shell would increase in thickness, the extent and frequency of these ruptures would probably lessen, as whatever may be the mechanical action producing them, it would then have an increased resistance to overcome. The ejected matter which would arrive at the surface would also probably not amalgamate so completely with the perfectly cooled solidified matter there, as the matter formerly ejected did when the solid surface was itself at a very high temperature. From the foregoing considerations, it appears that a value of a_1 less than the present semipolar axis of the earth would be at least as much in accordance with observed geological phenomena as a value greater than that semiaxis. The protrusion of the primary and igneous rocks through the strata composing the external crust of the earth, would be in some measure a necessary consequence of the smaller value of a_1; and it would not follow that the surface of the earth should necessarily undergo any great contortions.

In either of the cases which have been just examined, the arrangement of the molecules constituting the fluid globe should be different from their present arrangement. Their arrangement may or may not be different, if the value of a_1 coincided with the present semipolar axis of the earth, in so far as the value of a_1 would have any influence upon that arrangement.

If the dimensions of the globe had been increasing in the manner which should happen if a_1 had at first a small value, the rate of that increase could be determined by finding the areas of the fissures through which the fused matter may have been ejected during the progress of the different geological formations. The geometrical relations between the surface of the spheroid and its axes would evidently be of some assistance in the course of such an investigation. If the sum of the areas of these fissures was small, compared with that of the surface of the earth, then it may be generally concluded that a_1 could not be much less than the present semipolar axis of the terrestrial spheroid.

The three following general conclusions may be now stated as deductions from the foregoing remarks:—

1. If a_1 were greater than the present semipolar axis of the earth, the difference should be small.

2. If a_1 were less than that semiaxis, it becomes more difficult to assign a limit to their difference, but it appears probable that this difference would be greater than what it would be in the foregoing case.

3. The value of a_1 may be identical with that of the present semipolar axis without contradicting any properties of the primitive fluid mass of which we may be aware, or without discordance with geological phenomena.

In order that the value of a_1 should be greater than the present semipolar axis, it is evident that the fluid should have either a low density or a small compressibility. If a_1 were, on the contrary, much less than that semiaxis, the specific gravity of the fluid should be high or its compressibility should be great. If a_1 were equal to the semipolar axis, the fluid's compressibility should still be small compared with those of all the fluids, except mercury, upon which experiments have been made, unless its density were much less than the mean density of the present external crust of the earth.

The above considerations, in addition to what have been previously presented, appear to prove that a_1 could not much exceed the present semipolar axis of the earth, and that if a_1 differed in any way from that semiaxis the difference would most probably be owing to the comparative smallness of a_1.

8. The application of equations (5.) or (6.) to the determinations of the earth's ellipticity, may now be attempted before proceeding to any further investigations. In making use of (6.) or any other similar equation for the determination of the ellipticity of the spheroid, the numerical results should be always considered as hypothetical. Such an equation could not give the present ellipticity, unless that which the earth had immediately after the solidification of the outer coat of the shell had remained unaltered. It is not improbable that many causes may have existed to produce such an alteration.

If from any cause the fluid nucleus exerted unequal pressures upon different parts of the shell, it is evident that their tendency would be to alter its form. It is possible to conceive that any alteration so produced in the figure of the earth may consist in a reduction as well as in an increase of its ellipticity. In a more advanced stage of these researches I may be able to fully consider the influence of such causes. It is enough for the present to point out the possibility of their existence.

If it be admitted that the causes which have been referred to in the foregoing paragraphs are of sufficient importance to produce appreciable changes in the general figure of the earth, it must appear at least a doubtful assumption to assign to n such a value in the expression for the density of the strata of the primitive fluid, as that which would give precisely the same ellipticity as the present.

In order to illustrate the application of equation (6.) and to show that from its form a change in the value of n can make but a comparatively small change in the value of E, I shall now proceed to find an expression for Q.

If the dimensions of the fluid mass be supposed to be the same as those of the earth at present, then g' will be the same as g, gravity at the period of its fluid state.

It is evident that $\varphi(a)$ can be expressed under the form

$$\varphi(a)=\frac{\psi(a)}{\mathrm{I}^2},$$

where

$$\mathrm{I}=\frac{8}{3}\pi\int_0^{a_1}\varrho a^4 da.$$

When a_1 is taken as unity, we shall have

$$\psi(a)=\frac{\frac{5}{2}\left(1-\frac{3q}{n^2}\right)}{\left(3-q-\frac{n^2}{q}\right)},$$

where for brevity q is used instead of $1-\frac{n}{\tan n}$; but when $\varrho=\frac{\mathrm{A}}{a}\sin an$,

$$\int_0^1 \varrho a^4 da=\frac{\mathrm{A}}{n^4}[(n^2-6)q+2n^2a^2],$$

but

$$A=\frac{\varrho'}{\sin n}, \quad D=\frac{3q\varrho'}{n^2}, \quad M_1=\frac{4}{3}\pi D,$$

hence

$$I=\frac{2}{3}\frac{M_1}{qn^2}[(n^2-6)q+2n^2] ;$$

whence, finally,

$$\varphi(a)=\frac{45}{8M_1^2}\cdot\frac{q^2\left(1-\frac{3q}{n^2}\right)}{\left\{2\left(1-\frac{3q}{n^2}\right)+q\right\}^2\left(3-q-\frac{n^2}{q}\right)}.$$

If this expression be written in the form

$$\frac{45}{8}\frac{K}{M^2}=\varphi(a),$$

then $Q=\frac{9}{10}K$, and (5.) will become

$$E=\frac{9}{10}\frac{m'K}{\sigma'^2}. \quad \ldots\ldots\ldots\ldots\ldots \quad (11.)$$

In making use of either (6.) or (11.), a quantity P is introduced which depends upon certain numbers obtained from observation. One of these numbers is the ratio of the earth's mass to that of the moon, and some uncertainty seems yet to exist as to its value*. The results obtained from using in (6.) or (11.) the different values of this number, which may be obtained by different methods, are much affected by their differences.

In order to compare equation (6.) with that used in the Mécanique Céleste for finding the earth's ellipticity, the following calculations have been made.

If the equation in the Mécanique Céleste be used, we shall have

$$\begin{cases} n=\frac{5}{6}\pi, & E=\frac{1}{305} \\ n=\frac{11}{12}\pi, & E=\frac{1}{336}. \end{cases}$$

If equation (6.) be used,

$$\begin{cases} n=\frac{5}{6}\pi, & E=\frac{1}{308} \\ n=\frac{11}{12}\pi, & E=\frac{1}{317}. \end{cases}$$

The value of P which has been used in the application of (6.) is that which is given in equation (*k*.), Livre V. of the work of M. De Pontécoulant.

9. After the formation of the external shell of the earth, the entire mass composed of that shell and of the internal fluid nucleus, may be supposed to rotate about an axis not differing much in position from the present terrestrial axis of rotation. If the angular velocities of the shell and nucleus about this axis were from any cause

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* Pontécoulant, Théorie, &c., tom. iv., Note 3, p. 651.

different at first, it seems probable that the influence of friction, and of the cohesion of their surfaces of contact, would at length establish an uniform motion for the whole mass. The direct influence which the rotatory motion of the shell and nucleus may exercise upon geological phenomena, will not require therefore the motions of both to be separately considered.

The examination of the motions of the shell and nucleus, and of their mutual actions, whether directly, or from the influence of exterior disturbing causes, may therefore be comprehended under the following divisions:—

1. The phenomena attending the rotation of the entire mass during the gradual solidification of the shell.

2. The pressures exerted by the fluid upon the interior surface of the shell, whether from molecular action, the agency of the heavenly bodies, or from centrifugal force.

3. The influence of the changes of temperature which may occur during the solidification of the shell in contracting or expanding its parts, and in producing physical changes in its interior structure.

From the intimate connexion between the first and second of the above divisions, it would be impossible to examine one of them in a perfectly general manner without introducing the consideration of the other. The complete consideration of both could with great advantage be treated in another memoir than in the present, and I hope soon to have it in my power to complete all the necessary investigations. It will be enough for the present to indicate the importance of the first division in a geological point of view, by referring to one of the phenomena comprehended under it. If from the formation of the solid shell, and from the gradual diminution in the mass of the fluid nucleus, any change should be produced in the moment of inertia of the whole mass with respect to its axis of rotation, the angular velocity of the globe about its axis would be changed. The manner in which the solidification of the mass may take place, and the probable constitution of the fluid, will determine how far such a change may extend. If such a change should be great, it would exert an important influence upon the motions of the liquids or gases surrounding the earth, and upon a multitude of organic phenomena which its surface may have presented at different times.

XXII. *Researches in Terrestrial Physics.*—Part II. *By* HENRY HENNESSY, *M.R.I.A. &c. Communicated by Major* LUDLOW BEAMISH, *F.R.S.*

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Preliminary Remarks.

IN the first part of these researches, I have endeavoured, by generalizing the hypothesis on which is usually founded the theory of the earth's figure, not only to improve that theory, but also to establish a secure basis for researches into the changes which may have taken place within and at the surface of the earth during the epochs of its geological history. Although I stated that no precise physical evidence could be adduced for the examination of the assumption that the molecules of the primitive fluid, supposed to have constituted the earth, retained their positions after solidification, it yet appears that such evidence exists, if we may be permitted to draw any conclusions relative to the physical properties of substances in the earth's interior, from the observed physical properties of substances at its surface. Professor BISCHOF of Bonn, has shown* that Granite contracts in volume in passing from the fluid to the solid crystalline state, from 1 to ·7481, Trachyte from 1 to ·8187, and Basalt from 1 to ·8960. The first of these rocks appears, as far as can be observed, to constitute the greater part of the earth; hence the assumption alluded to must be considered not only as superfluous, but as erroneous.

In this Part it is my object to discover relations between the interior structure of the earth and phenomena observed at its surface, and also the effects of the reaction of the fluid nucleus, described in Article 6, Part I., upon the solid crust. I divide this Part into sections, each containing a distinct investigation, the order of arrangement of these sections being determined according to their fundamental importance. The statement of the geological results capable of being deduced from these investigations is, for greater clearness, reserved for the end. Such of these results as chiefly depend on the validity of the reasonings used in Section III. are presented with some diffidence, owing to the imperfect experimental knowledge we possess respecting the subjects discussed in that section. The diminution of the earth's mean radius by refrigeration is neglected all through, except where the contrary is specially mentioned.

I. THE PRESSURES OF THE SHELL AND NUCLEUS AT THEIR SURFACE OF CONTACT.

1. In this investigation the earth is supposed to consist of a nucleus of fluid matter inclosed in a solid shell. The inner and outer surfaces of the shell are sup-

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* LEONHARD und BRONN's Neues Jahrbuch, 1841, p. 565. See also a paper by the same writer in the N. Jahrbuch for 1843, p. 1. These results seem also to be confirmed by others subsequently found by M. DEVILLE.

posed to be spheroidal, oblate, and nearly spherical. Both shell and nucleus are supposed to be formed of strata increasing in density, according to unknown laws, as the radii of these strata decrease.

If the earth were solid from its surface to its centre, all the phenomena of its rotation could be determined by the integration of three differential equations relative to its motion about its centre of gravity, and of three more relative to the motions of its principal axes referred to three rectangular axes fixed in space. The constants contained in these equations would depend on the attractions of exterior bodies, on the impressed forces, and on the arrangement of the particles composing the earth. It is evident that similar equations would suffice for the case of an empty shell constituted in the manner above mentioned, after the substitution of the constants depending on the magnitude and internal constitution of the shell for those depending on the magnitude and internal constitution of the entirely solid spheroid. By adopting this method, no new analytical transformations are required in discovering the phenomena of the shell's independent rotation, for we can thus avail ourselves of the researches already made by geometers relative to the rotation of the entirely solid spheroid. I have therefore thought it sufficient for our present purposes to merely present the following conclusions to which I have arrived, by using the method above indicated.

1st. If the original impressed forces were the same in direction and intensity for the shell as for the entirely solid spheroid, the angular velocity of the former about its instantaneous axis would be greater than the angular velocity of the latter about its instantaneous axis.

2nd. The influence of exterior disturbing forces would be insensible relative to the rotation of the shell about its centre, provided that its strata possess nearly similar laws of arrangement with those of the solid spheroid.

3rd. The motions in space of the axes of the shell due to the action of exterior disturbing bodies, would be affected to a greater degree than similar motions of the axes of the solid spheroid.

If no other forces acted on the fluid nucleus besides the attractions of its own particles, the attraction of the shell, and centrifugal force, its surface would be an ellipsoid of revolution, and it would rotate steadily about the axis of its greatest moment of inertia. If the action of exterior disturbing bodies be added to these forces, tidal oscillations in the surface of the nucleus would tend to be produced; but it is evident, that unless the disturbing forces were very great, the position in space of the axis of rotation of the mass would be much less affected than if it existed in the solid state. Let, in addition to the forces already enumerated as acting on the fluid nucleus, certain molecular forces be conceived to act on its particles, by which the whole mass might in general acquire a tendency to expand or contract, and also to change its form. This class of forces may be conceived to be resolved into two pressures acting at the inner surface of the shell, one of them being supposed to be constant for every point, and the other variable. If, moreover, the constitution of the shell and nucleus should be favourable to a great amount of friction at their surface of contact, it is at least possible to conceive that if the sum of the pressures existing at the same surface be sufficiently great, the whole mass might rotate nearly as if solid from its surface to its centre. As it will hereafter appear that such conditions must almost necessarily exist, it is superfluous for our present object to further examine the general problem of the rotation of the shell and nucleus. I shall therefore proceed to consider the pressures which might take place at the surface of contact of the shell and nucleus.

2. Abstracting the action of exterior disturbing bodies, the pressure of the nucleus at the inner surface of the shell will result from the attractions of all the particles of the shell and nucleus, centrifugal force, and molecular actions. Unless the last mentioned class of forces should have a tendency to disturb the position of the axes of rotation of the shell and nucleus, it is plain that these axes may be considered as coincident.

Of the two resultant pressures mentioned in the preceding article, it is evident that the variable pressure may be conceived to result from the difference in form of the free surface of the nucleus and the shell's inner surface. If these surfaces be very nearly spheroids of revolution, described about the shell's axis of rotation, it follows that the greatest pressure will be at the equator or poles of the shell, according as the tendency of the nucleus may be to become more or less oblate. In either case it is evident that every point on certain lines situated between the equator and poles will not be subjected to any pressure from this cause, or in other words, the sum of all the pressures at the points in question will be equal to the constant pressure. The general expression for the pressure at any point of the shell may therefore be made to contain the coordinates of the lines in question as constant quantities. As these lines in the case considered are evidently circles parallel to the equator of the shell, we may call them the parallels of mean pressure.

Let a straight and indefinitely narrow canal of fluid be conceived to reach from the centre to the surface of the nucleus. Let the origin of the coordinates of any point in it be fixed at the centre of gravity of the mass, and let the plane of x, y be perpendicular to the axis of rotation. Let r represent the radius drawn from the origin to a molecule in the canal, θ the angle made by this radius with the axis of rotation, and ω the angle formed by the projection of the radius on the plane of x, y with the axis of y; then

$$z=r\cos\theta,\quad y=r\sin\theta\cos\omega,\quad x=r\sin\theta\sin\omega.$$

The pressure p at the point in the canal having these coordinates will be expressed by the equation

$$dp=\varrho[\mathrm{X}dx+\mathrm{Y}dy+\mathrm{Z}dz+\alpha^2(xdx+ydy)],$$

in which, as in art. 2, Part I., X, Y, Z represent the components of the attractions parallel to the three rectangular axes of x, y and z, α the angular velocity of rotation of the nucleus, and ϱ the density at the point in the canal. This equation may be written as follows, after the substitution of the above values, and it being remembered that θ and ω are constant for the canal,

$$dp=\varrho(dV+\alpha^2\sin^2\theta.rdr),$$

V being a function of r, θ and ω. On integration this gives

$$P-P'=\int_0^r\varrho dV+\alpha^2\sin^2\theta\int_0^r\varrho rdr,$$

P standing for the pressure on an unit of surface of the stratum of the nucleus having the radius r, and P'_0 the pressure at the centre. With the angular velocity a_1, all other things remaining as before,

$$P''-P'''=\int_0^r\varrho dV+a_1^2\sin^2\theta\int_0^r\varrho rdr.$$

But when θ becomes θ_1, its value at the parallel of mean pressure,

$$P'=\Pi-\int_0^{r'}\varrho dV-a^2\sin^2\theta_1\int_0^{r'}\varrho rdr,$$

$$P'''=\Pi-\int_0^{r'}\varrho dV-a_1^2\sin^2\theta_1\int_0^{r'}\varrho rdr,$$

Π representing the constant pressure on the stratum in question, and r' the value of r at the parallel of mean pressure. If α_1 be that angular velocity which would cause the surface of the nucleus to coincide with that of the shell $P''=\Pi$, we shall obtain by combining the foregoing expressions and neglecting the difference between r and r',

$$P=\Pi+(\alpha^2-\alpha_1^2)(\sin^2\theta-\sin^2\theta_1)\int_0^r\varrho rdr. \qquad (1.)$$

For the pressure P_1 at the shell's inner surface, we shall have

$$P_1=\Pi_1+(\alpha^2-\alpha_1^2)(\sin^2\theta-\sin^2\theta_1)\int_0^{r_1}\varrho rdr, \qquad (2.)$$

r_1 and Π_1 representing respectively the radius and pressure at the surface stratum of the nucleus. If Π_1 be not negative, this expression will be always positive with respect to some portion of the shell's inner surface; for when $\alpha \; 7 \; \alpha_1$ the greatest pressure is at the equator, and $\theta \; 7 \; \theta_1$; when $\alpha \angle \alpha_1$, the greatest pressure is at the poles, and consequently $\theta \angle \theta_1$.

3. The determination of θ_1 may be thus easily effected. Let the equations of the generating ellipses of the surfaces of the nucleus and shell be respectively

$$A_1^2x^2+B_1^2z^2=A_1^2B_1^2, \quad A_2^2x'^2+B_2^2z'^2=A_2^2B_2^2,$$

A_1, B_1 and A_2, B representing respectively the less and greater axes of these surfaces. The volumes contained within these surfaces being equal, we have $A_1B_1^2=A_2B_2^2$, and hence at the parallels of mean pressure, where $x=x'$ and $z=z'$,

$$z=\pm A_1A_2\sqrt{\frac{B_1^2-B_2^2}{B_1^2A_2^2-B_2^2A_1^2}}.$$

This expression shows that the parallels of mean pressure are symmetrically situated at each side of the equator.

If for z its value be substituted, and the condition of equality of volumes be remembered, we shall obtain

$$\cos\theta_1 = \pm\frac{A_2}{\sqrt{A_1^2+A_1A_2+A_2^2}}, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3.)$$

r_1 being supposed to differ very little from A_1.

If the changes in the oblateness of the nucleus be small, $\cos\theta_1$ will be nearly constant, and the parallels of mean pressure will oscillate but slightly about their mean position. Hence if $A_2=A_1(1+\varepsilon)$, ε will be a very small quantity depending on the difference of the ellipticities of the two surfaces, but by TAYLOR's theorem

$$F(A_2)=F(A)+\varepsilon F'(A)+\frac{\varepsilon^2}{1.2}F''(A_1)+\ldots.$$

Hence if the surface of the shell should change with every change of form of the nucleus, ε will be infinitely small, and consequently

$$\cos\theta_1=\pm\frac{1}{\sqrt{3}}. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4.)$$

If the surface of the shell should not change its form for every change in form of the nucleus, ε might yet be so small as to be negligible compared with other quantities entering into our analytical expressions, and hence in such a case the above expression for θ_1 will be approximately true.

As θ_1 is the complement of the latitude at the parallel of mean pressure, we may conclude from the preceding investigation, that, *at the parallel the square of the sine of the latitude of which is one-third, the pressure of the fluid is always the same as if the surface of the nucleus were one of equal pressure for the shell.*

Hence if we represent by f the centrifugal force at the equator of the shell's outer surface, where the radius is supposed equal to unity, and by f_1 its value corresponding to a_1, equation (1.) becomes

$$P=\Pi-(f-f_1)\left(\cos^2\theta-\frac{1}{3}\right)\int_0^a \varrho a da, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5.)$$

where a_1 represents the radius of a sphere equal in volume to the spheroid included within the stratum of the nucleus with the radius r, and which consequently differs but little from r.

The simple expressions for the pressure on any stratum of the nucleus and on the shell's inner surface obtained in this section, will be found useful in the course of these researches, and particularly in the succeeding section.

II. THE VARIATION OF GRAVITY AT THE EARTH'S SURFACE.

4. It is in general evident, that if the laws of arrangement of the molecules composing the shell and nucleus be different, the variation of gravity at the surface of

the former will not be the same as if in solidifying all the particles retained the same positions which they had when constituting the entirely fluid mass. All investigations heretofore made of the variation of gravity at the earth's surface being grounded on this very untenable hypothesis, it seems desirable that a more general solution of the question should be obtained, in which such a supposition would not be involved.

The forces acting on a particle at the shell's outer surface which we have here to examine, are—1st, the shell's attraction; 2nd, the attraction of the nucleus; 3rd, centrifugal force. If the laws of arrangement of the matter composing the shell be continuous, the first of these forces will be equal to the difference between the attraction of the entirely solid spheroid and that of the spheroid produced by the complete solidification of the nucleus, the particles in both spheroids arranging themselves according to the influence of the forces acting on them.

5. *Attraction of the Shell.*—In a spheroid differing but little from a sphere, and composed of homogeneous strata varying in form and density, the expression upon which its attraction on an exterior point depends, is thus written*,—

$$V=\frac{4\pi}{r'}\int_0^{a'}\varrho_2 a^2 da+\frac{4\pi\beta}{r'}\int_0^{a'}\varrho_2 d\left(a^3W_0+\frac{a^4}{3r}W_1+\&c.\right), \quad \ldots\ldots \quad (6.)$$

the radius of each stratum being of the form $a(1+\beta w)$, a being the radius of the sphere equal in volume to the mass included within the surface of that stratum, and $w=W_0+W_1+W_2+\&c.$, W_0, W_1, &c. being functions satisfying the equation of LAPLACE's coefficients, ϱ_2 the density of any stratum, a' the value of a at the surface, and r' the radius of the attracted point.

If the above expression be supposed to refer to the spheroid included within the shell's outer surface, it is evident that a corresponding expression may be obtained for the spheroid included within the shell's inner surface by merely changing β into β', and a' into a_1; β' being a constant depending on the ellipticity of that surface, and a_1 the value of a corresponding to it, we shall have therefore

$$V_1=\frac{4\pi}{r'}\int_0^{a_1}\varrho_2 a^2 da+\frac{4\pi\beta'}{r'}\int_0^{a_1}\varrho_2 d\left(aW_0+\frac{a^4}{3r}W_1+\text{etc.}\right). \quad \ldots\ldots \quad (7.)$$

If (6.) and (7.) be differentiated with respect to r, and the first then subtracted from the second, we shall obtain for G_1, the attraction of the shell, the expression

$$G_1=\frac{4\pi}{r^2}\int_{a_1}^{a'}\varrho_2 a^2 da+\frac{4\pi}{r'^2}\left\{\beta\int_0^{a'}\varrho_2 d\left(a^3W_0+\frac{2a^4}{3r}W_1+\frac{3a^5}{5r^2}W_2+\ldots.\right)\right.$$
$$\left.-\beta'\int_0^{a_1}\varrho_2 d\left(a^3W_0+\frac{2a^4}{3r}W_1+\frac{3a^5}{5r^2}W_2+\ldots.\right)\right\} \quad \ldots\ldots \quad (8.)$$

Let us conceive the surfaces of both spheroids to be covered with a homogeneous fluid to a small depth compared with their radii. The bounding surfaces of these fluid strata will depend on the attractions of the spheroids, and also on the attractions of the fluid particles. If the density of each of these strata be nearly the same as that of the solid stratum in immediate contact with it, its superposition on the spheroid will evidently not much increase the mass of the entire attracting body. The equation of equilibrium at the surface of the fluid on the greater spheroid is

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* See PONTÉCOULANT, Théorie Analytique, &c., Livre V. No. 23.

$$\int_0^{a_1'}\frac{dp}{\varrho_2}=\frac{4\pi}{3a_1'}(1-\beta w)\int_0^{a_1'}\varrho_2 da^3+\frac{4\beta\pi}{a_1'}\int_0^{a_1'}\varrho_2 d\left[a^3\mathrm{W}_0+\frac{a^4}{3r}\mathrm{W}_1+\frac{a^5}{5r^2}\mathrm{W}_2+\text{etc.}\right]$$

$$+\frac{1}{3}fa_1'^2-\frac{1}{2}fa'^2\left(\cos^2\theta-\frac{1}{3}\right),$$

a_1' being the value of a' at the fluid's surface, and p the pressure on the stratum. On developing and then comparing similar terms, we obtain

$$\int_0^{a_1'}\frac{dp}{\varrho_2}-\frac{4\pi}{3a}\int_0^{a_1'}\varrho_2 d.a^3+\frac{4\pi\beta\mathrm{W}_0}{3a_1'}\int_0^{a_1'}\varrho_2 da^3-\frac{4\beta\pi}{a_1'}\int_0^{a_1'}\varrho_2 da^3\mathrm{W}_0-\frac{1}{3}fa_1'^2=0.$$

The strata of the shell being bounded by spheroids of revolution and the origin of the coordinates being at the centre of gravity,

$$\mathrm{W}i=0,$$

i being different from 2. From the equation for W_0, it can be immediately inferred that W_0 may receive an arbitrary value. For W_2 we obtain

$$\frac{4\beta\pi}{5a_1'^3}\int_0^{a_1'}\varrho_2 d.a^5\mathrm{W}^2-\frac{4\pi\beta\mathrm{W}_2}{3a_1'}\int_0^{a_1'}\varrho_2 da^3+\frac{1}{2}fa_1^2\left(\cos^2\theta-\frac{1}{3}\right)=0,$$

whence

$$\beta\mathrm{W}_2=-\beta h\left(\cos^2\theta-\frac{1}{3}\right), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9.)$$

in which

$$\beta h=mf(a_1'), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10.)$$

m standing for the ratio of centrifugal force to gravity at the equator, and f being a functional symbol. If we make $\mathrm{W}_0=-\frac{1}{3}h$, and substitute in the expression for r these values, we would have

$$r'=a_1'(1-\beta h\cos^2\theta),$$

and therefore βh must represent the ellipticity of the fluid stratum.

Similarly for the surface of the fluid stratum on the smaller spheroid, where $\overline{a}_1$ represents what $\overline{a}_1$ becomes for the fluid

$$r_1=\overline{a}_1(1-\beta' h\cos^2\theta), \quad \beta' h=mf(\overline{a}_1). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11.)$$

Besides these general expressions for $\beta\mathrm{W}_0$, &c., $\beta'\mathrm{W}_0$, &c., it is possible to find others in a particular case, which expressions will subsequently be found useful. The particular case referred to, is that in which the shell's strata are supposed to have all the same ellipticity. On this hypothesis W_0, W_1, &c. are not functions of a, and consequently (8.) becomes

$$\mathrm{G}=\frac{4\pi}{r^2}\int_{a_1}^{a'}\varrho a^2 da+\frac{4\pi\beta}{r^2}\left[3\mathrm{W}_0\int_0^{a'}\varrho a^2 da+\frac{8}{3}\frac{\mathrm{W}_1}{r}\int_0^{a'}\varrho a^3 da+\frac{3\mathrm{W}_2}{r^2}\int_0^{a'}\varrho a^4 da+\ldots\right]$$

$$-\frac{4\pi\beta'}{r^2}\left[3\mathrm{W}_0\int_0^{a_1}\varrho a^2 da+\frac{8}{3}\frac{\mathrm{W}_1}{r}\int^{a_1}\varrho a^3 da+\frac{3\mathrm{W}_2}{r^2}\int_0^{a_1}\varrho.a^4 da+\ldots\right].$$

From the values attributed to a' and a_1, W_0 will disappear, and from the origin chosen for the coordinates W_1 will also disappear*.

Let M represent the mass of the greater spheroid, I its moment of inertia with respect to its axis of rotation, M_1 and I_1 being the corresponding quantities relative to the smaller spheroid, then

$$G=\frac{M-M_1}{r^2}+\frac{\beta}{r^4}\left\{\frac{q}{2}IW_2+c_3W_3+\ldots\right\}-\frac{\beta'}{r^4}\left\{\frac{q}{2}I_1W_2+c'_3W_3+\ldots\right\},$$

c_3 and c'_3 being constant coefficients.

The artifice already employed may be used here in order to find expressions for βW_2, $\beta' W_2$, &c. In this case the equation of equilibrium of the fluid at the surface of the greater spheroid is

$$C=\frac{M'}{r'_1}\left\{1+\frac{\beta}{r'^2_1}\left[\frac{3}{2}\frac{I'}{M'}W_2+\ldots\right]\right\}-ra'^2_1f\left(\cos^2\theta-\frac{1}{3}\right),$$

M′ and I′ standing for the mass and moment of inertia respectively of the whole mass composed of the fluid stratum and solid spheroid. This becomes, on developing r, and making $C=\frac{M'}{a'_1}+\frac{a'^2_1}{3}f$,

$$\frac{\beta w}{a}=\beta\left[\frac{3}{2}\frac{W_2}{a^3}\frac{I}{M}+\ldots.\right]-\frac{a'^2f}{2M'}\left(\cos^2\theta-\frac{1}{3}\right).$$

But also

$$w=W_2+W_3+W_4+\ldots.+W_i.$$

The truth of these two simultaneous expressions requires that

$$W_2=\frac{3}{2}\frac{W_2}{a^2}\frac{I'}{M'}-\frac{a^3f}{2M\beta}\left(\cos^2\theta-\frac{1}{3}\right).$$

But $I=\frac{2}{5}\frac{Ma^2}{\sigma}$, σ being a number depending on the internal constitution of the spheroid, and $\frac{fa'^2}{M'}=m$ nearly; hence neglecting very small quantities, or making $a'_1=1$,

$$\beta W_2=-\frac{5\sigma m}{2(5\sigma-3)}\left(\cos^2\theta-\frac{1}{3}\right). \quad \ldots\ldots\ldots \quad (12.)$$

And in a similar manner we may obtain

$$\beta' W_2=-\frac{5a_1^3\sigma_1 m}{2(5\sigma_1-3)\mu_1}\left(\cos^2\theta-\frac{1}{3}\right), \quad \ldots\ldots\ldots \quad (13.)$$

μ_1 being used for brevity to represent $\frac{M_1}{M}$, and σ_1 being a number analogous to σ. Now if r be developed in (8.), and all terms of the order β^2 be neglected, it will become, remembering that $r'=a'(1+\beta y)$, y being a function of the polar coordinates of the point,

$$G_1=M\left\{1-\mu-\beta\left[2(1-\mu)y-\frac{q}{5}\left(\frac{1}{\sigma}-\frac{\mu\beta'a_1^2}{\beta\sigma_1}\right)W_2\right]\right.$$

$$\left.=M\left\{1-\mu+m\left[2(1-\mu)e-\frac{qm}{2(5\sigma-3)}\left(1-a_1^5\,\frac{5\sigma-3}{5\sigma_1-3}\right)\right]\left(\cos^2\theta-\frac{1}{3}\right)\right.\right., \quad \ldots\ldots \quad (14.)$$

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* See the work already cited, No. 21.

it being remembered that the surface of the earth is a spheroid of revolution,

$$\beta y=-e\left(\cos^2\theta-\frac{1}{3}\right),$$

e representing the ellipticity. The expression for the attraction of a homogeneous shell with surfaces of equal ellipticity, is evidently

$$G_1=M\left\{1-a_1^3+\frac{1}{2}\left[5(1-a_1^3)e-\frac{qm}{2}(1-a_1^4)\right]\right)\cos^2\theta-\frac{1}{3}\bigg)\bigg\}. \quad . \quad . \quad . \quad . \quad . \quad (15.)$$

6. *Attraction of the Nucleus.*—The forces acting on any stratum of the nucleus, by changing the arrangement of its particles, must in general influence their action on exterior bodies; hence to obtain the attraction of the nucleus, it is necessary to take all such forces into consideration. These forces are in the present case, the attractions and pressures of masses of fluid within and without the stratum, the attraction of the shell, and centrifugal force. Hence for any stratum we have the following equation of equilibrium,

$$\begin{aligned}\int\frac{dp}{p}=\frac{4\pi}{3r}\int_0^a \varrho da^3+\frac{4\beta\pi}{r}\int_0^a \varrho d\left(a^3Y_0+\frac{a^4}{3r}Y_1+\frac{a^5}{5r^2}Y_2+\text{ etc.}\right)\\ +2\pi\int_a^{a_1}\varrho d.a^2+4\beta_1\pi\int_0^{a_1}\varrho d\left(a^2Y_0+\frac{ar}{3}Y_1+\frac{r^2}{5}Y_2+\text{ etc.}\right)\\ +2\pi\int_{a_1}^{a'}\varrho_2 d.a^2+4\beta\pi\int_{a_1}^{a'}\varrho_2 d\left(a^2W_0+arW_1+\frac{r^2}{5}W_0+\text{ etc.}\right)\\ +\frac{1}{3}fr^2-\frac{1}{2}fr^2\left(\cos^2\theta-\frac{1}{3}\right),\end{aligned}$$

where p represents the pressure at any point in the stratum; Y_0, Y_1, &c. are functions of the coordinates satisfying the equation of Laplace's coefficients, and also possessing the property of forming the terms of the series into which the radius of the point may be developed.

But as the nucleus is inclosed in a rigid shell, its surface is constrained to take a form different from that which it would have if the shell were removed. The integral at the left side of the above equation is consequently variable. The conditions of equilibrium require that it should be constant, and these conditions may be fulfilled by separating the variable from the constant terms in that quantity and transposing the former terms to the right side, the quantities Y_0, Y_1, &c. being supposed to undergo any variations which may be required by the new conditions.

By article 2,

$$p=\Pi-(f-f_1)\left(\cos^2\theta-\frac{1}{3}\right)\int_0^a\varrho ada,$$

Π being such a pressure that

$$p_1=\Pi-(f-f_1)\sin^2\theta_1\int_0^{a_1}\varrho ada,$$

θ_1 being that value of θ which makes $p=\Pi$, and p_1 a function of a_1, and consequently a constant for the nucleus.

On developing $r=a(1+\beta y)$, and substituting the value of p, we obtain

$$\int_0^a \frac{dp_1}{\varrho}=\frac{4\pi}{3a}(1-\beta y)\int_0^a \varrho.da^3+\frac{4\beta\pi}{a}\left[\int_0^a \varrho d.a^3\text{Y}+\frac{1}{3a}\int_0^a \varrho.da^4\text{Y}_1+\frac{1}{5a^2}\int_0^a \varrho.da^5\text{Y}_a+\text{ etc.}\right]$$

$$+2\pi\int_a^{a_1} \varrho da^2+4\beta\pi\left[\int_a^{a_1} \varrho.da^2\text{Y}_0+\frac{a}{3}\int_a^{a_1} \varrho da\text{Y}_1+\frac{a^2}{5}\int_a^{a_1} \varrho d\text{Y}_2+\text{ etc.}\right]$$

$$+2\pi\int_{a_1}^{a'} \varrho da^2+4\beta\pi\left[\int_{a_1}^{a'} \varrho da^2\text{W}_0+\frac{a}{3}\int_{a_1}^{a'} \varrho da\text{W}_1+\frac{a^2}{5}\int_{a_1}^{a'} \varrho d\text{W}_2+\text{ etc.}\right]$$

$$-\frac{1}{2}(f-f_1)a^2\sin^2\theta-\frac{1}{2}fa^2\left(\cos^2\theta-\frac{1}{3}\right)+\frac{1}{3}fa^2.$$

But

$$y=\text{Y}_0+\text{Y}_1+\text{Y}_2+\ldots.\text{Y}_i.$$

Hence if this value be substituted in the above equation, and if after substitution, similar functions of θ and ω, the coordinates of the point in the nucleus be equated to zero, we shall find

$$\int\frac{dp_1}{\varrho}-\frac{1}{3}fa^2-\frac{1}{2}(f_1-f)a^2-\frac{4\pi}{3a}(1-\beta\text{Y}_0)\int\varrho d.a^3-\frac{4\ \pi}{a}\int_0^a \varrho da^3\text{Y}_0$$

$$-2\pi\left(\int_0^{a_1} \varrho da^2+\int_{a_1}^{a_1} \varrho_2 da^2\right)-4\pi\left(\beta\int_0^a \varrho.d.a^2\text{Y}_0+\beta\int_{a_1}^{a'} \varrho_2 da^2\text{W}_0\right)=0.$$

But (art. 5) as $\text{W}_0=0$, and $\int\frac{dp_1}{\varrho}$ is constant, this expression shows that Y_0 may receive an arbitrary value. $\text{Y}_1=0$ by the property of the centre of gravity, which is the origin of the coordinates. When $i=2$,

$$\frac{4\beta_1\pi a^2}{5}\int_a^{a_1} \varrho.d\text{Y}_2+\frac{4\beta_1\pi a^2}{5}\int_{a_1}^{a'} \varrho_2 d\text{W}_2-\frac{4\beta_1\pi}{3a}\text{Y}_2\int_0^a \varrho.da^3+\frac{4\beta\pi}{5a^3}\int_0^a \varrho.da^5\text{Y}_2$$

$$+\frac{1}{2}(f-f_1)a^2\cos^2\theta-\frac{1}{2}fa^2\left(\cos^2\theta-\frac{1}{3}\right)=0.$$

But we have already found

$$\beta\text{W}_2=-mf(a')\left(\cos^2\theta-\frac{1}{3}\right),$$

hence the above becomes

$$\frac{4\beta_1\pi a^2}{5}\int_a^{a_1} \varrho d\text{Y}_2-\frac{4\beta\pi\text{Y}_2}{3a}\int_0^a \varrho d.a^3+\frac{4\beta\pi}{5a^3}\int_0^a \varrho da^5\text{Y}_2+\frac{1}{2}\left(f_1\cos^2\theta-\frac{1}{3}f\right)a^2$$

$$-\frac{a^2m}{a}\Psi(a_1a')\left(\cos^2\theta-\frac{1}{3}\right),$$

where $\Psi(a_1, a')$ is a function depending on the attraction of the shell, or in other words, depending on the arrangement of the shell's strata.

When i is any number greater than 2, we have

$$\frac{4\pi a^i}{2i+1}\left[\beta_1\int_a^{a_1} \varrho\frac{d\text{Y}_i}{a^{i-2}}+\beta\int_{a_1}^{a'} \varrho_2\frac{d\text{W}i}{a^{i-2}}\right]-\frac{4\pi\beta}{3a}\text{Y}_i\int_0^a \varrho.da^3+\frac{4\pi}{(2i+1)a^{i+1}}\int_0^a \varrho da^{i+3}\text{Y}_i=0.$$

But as $\text{W}_i=0$, and as the surface of the nucleus is a spheroid of revolution, $\text{Y}_i=0$. At the surface of the nucleus

$$\frac{4\beta\pi}{5a_1^3}\int_0^{a_1}\varrho d.a^5\mathrm{Y}_2-\frac{4\beta\pi\mathrm{Y}_2}{3a_1}\int_0^{a_1}\varrho d.a^3+\frac{1}{2}a_1^2f_1\left(\cos^2\theta-\frac{1}{3}\right)-a_1^2m\Psi(a_1,a')\left(\cos^2\theta-\frac{1}{3}\right), \quad . \quad (a.)$$

because

$$f_1\left(\cos^2\theta-\frac{1}{3}\frac{f}{f_1}\right)=f_1\left(\cos^2\theta-\frac{1}{3}\frac{1}{1+f'}\right)=f_1\left[\cos^2\theta-\frac{1}{3}(1-f')\right],$$

where f' is a very small quantity, and where consequently f_1f' is a negligible product.

Solving (*a.*) with respect to $\beta_1\mathrm{Y}_2$, we obtain

$$\beta_1\mathrm{Y}_2=-\beta h\left(\cos^2\theta-\frac{1}{3}\right),\ (16.),\qquad \beta_1h=f_1\Phi(a_1)+a_1^2m\Psi(a_1,a'). \ . \ . \ . \ . \ (17.)$$

If we make $\mathrm{Y}_0=\frac{1}{3}h$ and substitute the value of y in r, we shall have

$$r=a_1(1-\beta h\cos^2\theta).$$

Hence $\beta h=e_1$, e_1 being the ellipticity of the surface of the nucleus, and consequently of the shell's inner surface.

The general form of the function upon which depends the attraction of the nucleus on an exterior point, may be found by substituting these values in (7.), having first changed ϱ_2 into ϱ and W_0, W_1, &c. into Y_0, Y_1, &c.; hence

$$\mathrm{V}_3=\frac{\mathrm{M}_1}{r'}\left\{1-\frac{e_1}{r}-\frac{e_1}{r^2}\left(\cos^2\theta-\frac{1}{3}\right)a_1^2\right\}+\frac{a_1^5}{r^3}\left[\frac{1}{2}f_1-m\Psi(a_1,a')\right]\left(\cos^2\theta-\frac{1}{3}\right), \quad . \ . \quad (18.)$$

assuming that the mass of the nucleus is equal to the mass of the solid spheroid included within its surface, having the same law of density as the shell. The truth of this assumption will appear more manifest further on.

7. If, in a similar manner, we substitute the values of $\beta\mathrm{W}_2$, &c., $\beta'\mathrm{W}_2$, &c. in (8.), then develope r in both (8.) and (18.), after the differentiation of (18.) we shall have the sum of the attractions of the nucleus and shell on a point at the shell's outer surface, by adding the resulting expressions. If to this sum we add the term produced by the centrifugal force, we shall have for G, gravity at any point of the surface having θ for the complement of its latitude, the expression

$$\mathrm{G}=\mathrm{G}'(1+\lambda\cos^2\theta), \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (19.)$$

where

$$\lambda=m\left[\frac{5}{2}-3\left(f(a)-\mu_1a_1^2f(a_1)\right)\right]+\frac{3}{2}\left[m_1-m(1+\Psi(a',a_1)\right]a_1^5+2e-3e_1\mu a_1^2, \quad . \ . \quad (20.)$$

all terms of the second order being as usual neglected, m_1 standing for the value of m corresponding to f_1, and G′ for gravity at the equator. When the mass is supposed to be entirely fluid $a_1=a'=1$, $m_1=m$, $\Psi(a')=0$, $\mu=1$, and consequently $\lambda=\frac{5}{2}m-e$, as should be expected. The foregoing is the most general expression for the variation of gravity at the earth's surface yet obtained; gravity at any point being expressed as a function of the latitude of that point, of the radii and ellipticities of the shell's inner and outer surfaces, and of functions depending on the constitution of the shell and nucleus. Its value is not merely speculative, for it will be found to assist in explaining certain apparent anomalies detected by observation in the variation of gravity at the earth's surface, as well as in pointing out the limits assigned by observation to the thickness of the solid crust.

III. THE LAWS OF DENSITY OF THE SHELL AND NUCLEUS.

8. The density ϱ of a stratum of the mass when entirely fluid has been shown in Part I.* to depend on the pressure to which it may be subjected, and to the molecular properties of the fluid. The density of a stratum of the nucleus must evidently depend on the same circumstances, and hence we may assume its expression to have the same general form as for the entirely fluid mass, but yet containing variable indeterminate coefficients.

If the solidification of the nucleus proceeded entirely from its centre to its surface no shell could at any time exist, and as it will appear that it could not simultaneously solidify both from its centre towards its surface, and from its surface towards its centre, we can here consider only the latter case. When the solidification of the nucleus proceeds in this manner, its superficial stratum in contact with the inner surface of the shell will be the first to assume the solid state. As solidification must proceed very slowly from the slowness of the refrigeration of the entire mass, it is evident that the thickness of the stratum may be considered indefinitely small compared with the radius of the nucleus. Let its density in the fluid state be ϱ_1, in the solid state ϱ_2, and let $\varrho_1 = k\varrho_2$, k being a function depending on the contraction of the fluid when solidifying.

If, in conformity with the preceding remarks, we assume

$$\varrho = \frac{c_1 \sin a n_1}{a},$$

c_1 and n_1 varying with a_1 the mean radius of the nucleus, we shall have to determine four quantities in order to arrive at a knowledge of the laws of density of the shell and nucleus. It appears, however, that the number of known conditions which these quantities must satisfy will not suffice for their complete determination, although it is possible to conceive how a new condition could be experimentally found by which the required number would be made up. For if the physical properties of the matter composing the earth's interior resemble those of the matter at its surface, the form of k could be found with some degree of approximation, by a series of experiments on the contraction of fused matter at different densities resulting from differences of pressure. The conditions which can be at present determined are easily found thus: If the law of density of the shell be continuous, which must result from its mode of formation, and if the variations of a' and a_1 from refrigeration be neglected, we shall have

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* Articles 6 and 7.

$$4\pi\int_0^{a'}\varrho_2 a^2 da=4\pi\left(\int_{a_1}^{a'}\varrho_2 a^2 da+\int_0^{a_1}\varrho a^2 da\right),$$

and consequently

$$\int_0^{a_1}\varrho_2 a^2 da=\int_0^{a_1}\varrho a^2 da, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21.)$$

$$\mathrm{C}_1=\frac{n_1^2\int_0^{a_1}\varrho_2 a^2 da}{\sin a_1 n_1-a_1 n_1\cos a_1 n_1};$$

and from the condition $\varrho_1=k\varrho_2$,

$$k=\frac{\frac{n_1^2}{a_1\varrho_2}\int_0^{a_1}\varrho_2 a^2 da}{1-a_1 n_1\cot a_1 n_1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22.)$$

9. Let now an indefinitely thin canal of fluid be conceived to reach from the centre in a straight line to the surface of the nucleus, and consequently to pass through the surface stratum having the thickness da_1. Conceive this stratum to consist of an infinite number of elementary parallelopipeds, having their bases resting against the shell's inner surface. As the oscillations of the shell's surface are small, the simultaneous contraction of all these parallelopipeds can take place only in a direction perpendicular to their bases, and consequently da_1 will become $k_1 da_1$, k_1 being the cubical contraction of a mass of the fluid composing the stratum. The increase in volume of the shell, by the addition of the new stratum, will be less than the decrease in volume of the nucleus by its abstraction from its mass; and hence the nucleus must tend to expand in order to fill the empty space which would otherwise exist. This would evidently result as a necessary consequence of the cause of the variation in density of the strata from its centre to its surface.

The radius of the nucleus after the solidification of its superficial stratum being a_1-kda_1, and it being manifest that the entire mass of the nucleus before the solidification took place is equal to the mass of the solid stratum with the thickness kda_1, and the mass of the new nucleus,

$$\int_0^{a_1}\varrho a^2 da=\int_0^{a_1-kda}\varrho' a^2 da+\int_{a_1-kda_1}^{a_1}\varrho_2 a^2 da,$$

or

$$\int_{a_1-kda_1}^{a}(\varrho_2-\varrho)a^2 da-\int_0^{a_1-kda_1}(\varrho-\varrho')a^2 da=0,$$

where ϱ' is the density of the stratum with the radius a, after the solidification of the superficial stratum. As ϱ_2 and ϱ are constant in the interval $k_1 da$, we have

$$(\varrho_2-\varrho_1)k_1 a_1^2 da_1=\int_0^{a_1-k_1 da_1}(\varrho-\varrho')a^2 da. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23.)$$

But ϱ being a function of a, and ϱ' being what this function becomes after the expansion of the stratum to which it refers, we may write

$$\varrho=f(a),\ \varrho'=f(a+c_1 k_1 da),$$

c_1 being indeterminate, hence

$$\varrho-\varrho'=-c_1k_1\frac{d\varrho}{da}da-\frac{c_1^2k_1^2}{1.2}\,\frac{d^2\varrho}{da^2}da^2-\ldots.$$

consequently (23.) becomes after substitution and differentiation with respect to a_1,

$$\frac{d\varrho_2}{da}-c'\frac{d\varrho_1}{da}+\frac{2(1-k_1)}{a}\varrho_2=0, \qquad (24.)$$

neglecting terms of the second order, and making $c_1-1=-c'$.

If we assume $\varrho_2=\frac{\mathrm{C}_2\sin a_1n_2}{a_1}$, C_2 and n_2 being constants, and make $q_1=1-a_1n_1\cot a_1n_1$, $q_3=1-a_1n_2\cot a_1n_2$ (24.) becomes

$$1-k_1-\frac{1}{2}q_3+\frac{1}{2}c'-\frac{\varrho_1}{\varrho_2}q_1=0\,;$$

but as k_1 and k are evidently identical, we shall obtain after reduction

$$k=\frac{q_3-2}{c'q_1-2}, \qquad (25.)$$

whence

$$c'=q_2-\frac{2[1-(k)]}{(k)q}, \qquad (26.)$$

in which

$$q=1-n\cot n,\ \ q_2=1-n_2\cot n_2,$$

n being the value of n_1 at the surface of the entirely fluid mass, and (k) the value of k determined by experiment at the surface under atmospheric pressure.

But from (22.) we have

$$k=\left(\frac{n_1}{n_2}\right)^2\frac{q_3}{q_1}; \qquad (27.)$$

hence for the determination of n_1 we obtain

$$n_1^2\left(c'-\frac{2}{q_1}\right)=\left(1-\frac{2}{q_3}\right)n_2^2. \qquad (28.)$$

In obtaining these results, some assumptions had to be made which in the absence of experimental data can be considered only provisional; but it will be satisfactory to perceive that the results themselves seem to be in accordance with what we would expect from known physical laws. When $a_1=0$, $q_1=0$, $q_3=0$ and $k=1$, its greatest value, k consequently increases as the thickness of the shell increases, or as the density of the surface stratum of the nucleus increases. But the cubical contraction is equal to the cubical dilatation of the mass if reduced again to the fluid state under the same pressure, and by a recognized physical principle the dilatation of a body is equal to its resistance to compression, or inversely proportional to its compressibility. But the compressibility of a stratum of the nucleus decreases as its density increases, hence the above result appears to be in conformity with an observed physical law.

Equation (28.) may be thus written,

$$m'^2\left(c'-\frac{2}{q_1}\right)=a_1^2n_2^2\left(1-\frac{2}{q_3}\right), \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (29.)$$

making $n_1=\frac{m'}{a_1}$; from which it is evident that m' decreases with a_1, and consequently that the less the volume of the nucleus, the more does it approach the state of homogeneity.

10. If any grounds existed for believing that experiment could never even approximately disclose the laws of density and contraction of the matter composing the earth's interior, we should not be justified in attaching much importance to any hypothesis, however plausible, which may be formed relative to the forms of these laws. Such grounds would partially exist as long as doubts could be formed relative to the great or small specific density of the matter of the earth's interior. The variation in density of the spheroidal strata composing the earth, could be due to an accumulation near its centre of substances possessing a high specific density. From what we know of the matter composing the earth, I believe that almost all substances having a density much greater than that of the outer portion of its crust are metals, bodies which from their chemical nature do not probably exist to any great extent within the globe. Recent experiments tend to show that many metals are but compound radicals which exist only under certain conditions, and it is probable that the constituents of any one of these radicals have densities less than that of the metal itself. KANE, LAURENT and GERHARDT are of opinion, for instance, that the known metals do not exist in their oxides, but are eliminated when the oxides are decomposed. The metals alluded to are also simple bodies in the sense generally used, namely, that of being the lowest terms as yet known of compound bodies. Recent chemical researches seem to show that such simple bodies existed in the earth's primitive state, even in less quantity than we can at present discover them*. The chemical laws in virtue of which this would be true, would under certain conditions act as well in the interior as at the earth's surface, if we are entitled at all to admit their generality, and hence we must conclude that the specific density of the substances in the earth's interior must be subordinate to the effects of mechanical and physical causes in producing the observed variation in the density of its strata.

IV. THE FORMS OF THE STRATA OF THE SHELL.

11. As every stratum of the shell was originally the surface stratum of the fluid nucleus, its form must depend on that of the shell's inner surface, and of the isothermal surfaces passing through its poles and equator. At first I shall abstract the influence of the isothermal surfaces in order to simplify the problem of the determination of the form of the stratum.

As in art. (1.), the shell is here supposed to be rigid, and to be perfectly filled with the fluid matter, but here we cannot consider the transition from solidity to fluidity as abrupt. Many physical analogies lead us to believe that, on the contrary, this transition must be gradual, or that a stratum of matter not completely fluid must exist between the highly fluid matter of the nucleus and the solid matter of the shell. The transition from this imperfectly fluid stratum to the perfectly fluid matter within it, will be also gradual, but it is possible to conceive that a portion of it in immediate contact with the shell may merely possess that kind of fluidity which in solids would be considered extreme softness. This matter will cohere to the shell with a considerable force, compared to the cohesion of the fluid particles; and this fact, combined with its viscidity, must serve to remove any doubt as to its not being subjected to the same hydrostatical laws as the perfect fluid. If now a surface be conceived to exist which may be called the effective surface of separation of the perfect from the imperfect fluid, it is evident that its form will depend on the pressures which the former tends to exert.

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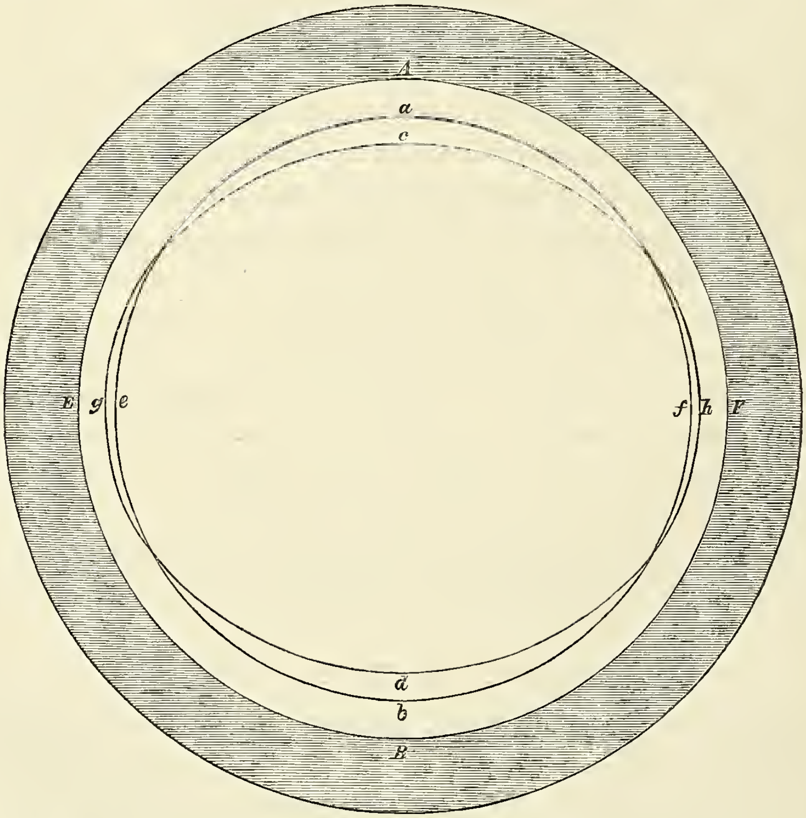
* See BISCHOF, Lehrbuch der Chem. und Phys. Geologie, Bd. I. s. 584, and Bd. II. s. 6.

Let AEBF in the accompanying figure represent the profile of the inner surface of the shell, *aebf* of the similar and concentric surface of the perfect fluid. In this case the pressure exerted by the nucleus would be the same for all points of the shell, and the thickness of the stratum of imperfect fluid would be everywhere the same. If, however, the pressure of the perfect fluid were not constant, its surface would tend to assume a different form, in order to re-establish equilibrium; it might



for example, tend to assume the form of which *cgdh* is the profile. The thickness of the stratum of imperfect fluid would then be greatest at A, and least at E.

On solidifying, the new stratum thus added to the shell would have the same proportional thickness, and its interior surface would in this particular case be more elliptical than its exterior surface. If, as seems extremely probable, the imperfectly fluid stratum be thin, and if it strongly adhere to the shell, it will exercise no sensible pressure on the perfect fluid, and must consequently take the form impressed on it without any sensible resistance.

12. It can be easily shown that in general the pressure of the perfect fluid will not be constant. Let a spheroidal mass of fluid be conceived, consisting of nearly similar spheroidal strata, these strata increasing in density as their radii decrease. The ellipticities of the bounding surfaces of any stratum will depend on the constitution and thickness of the strata outside it. If possible let the mass outside the stratum be removed, without altering the law of density of the remaining fluid: it is manifest that equilibrium will be obtained only where the surface of the stratum at any point becomes perpendicular to the resultant of all the forces acting on that point. With the same law of density as the entire mass, and urged by the same forces, the ellipticity of its surface must be the same as that of the surface of the primitive mass. If, however, the law of density changed in such a way as to render the remaining fluid more homogeneous, the ellipticity of its surface would be greater than that of the primitive fluid spheroid*. Hence we may conclude—(1.) that if the angular velocity and law of density of the nucleus remained unchanged after the formation of the first stratum of the shell, the outer and inner surfaces of that stratum would be similar, and its attraction on the interior mass would consequently, by a well-known theorem, be evanescent. The next formed stratum would thus also have similar surfaces, and so on with every stratum, until the mass should have completely solidified. In this case, therefore, the surfaces of all the strata would have the same ellipticity as the outer surface. (2.) If the forces acting on the nucleus after the solidification of the first stratum of the primitive fluid were such as to give the surface of the nucleus a tendency to become less oblate, the ellipticity of the interior surface of the imperfectly fluid stratum would be less than that of its exterior surface, and the resulting attraction of the shell after the solidification would manifestly tend to increase in the same direction the effect of the forces previously in action. (3.) If, on the contrary, the resultant of all these forces were such as to increase the oblateness of the perfect fluid, it is evident, from the preceding considerations, that the inner surface of the shell so produced would always be more elliptical than its outer surface.

These conclusions will be necessarily modified when the influence of the isothermal surfaces in the interior of the spheroid is considered. It seems that no complete and general solution of the problem of finding the forms of these surfaces has been yet achieved, but an approximate solution, founded on an hypothesis to which no weighty objections can be urged, has been given by Mr. Hopkins*. This solution will suffice for my present purpose, particularly when I only refer to the general result of his analysis. The result in question is, that the oblateness of the isothermal surfaces increases with their distance from the earth's surface. This result, combined with the first of the three conclusions in the foregoing paragraph, seems to show that if the earth solidified from its surface to its centre without changing its law of density, the ellipticity of the shell's inner surface would be greater than that of its outer surface. The truth of the second conclusion would be considerably weakened, while that of the third would be strengthened to the same amount.

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* See Poisson, Mécanique, ii. p. 546, 2nd edition.

13. It will immediately appear that this last is the conclusion which must be definitely adopted, if we admit that the matter composing the nucleus becomes denser in assuming the solid state.

Using the notation of art. 6, and neglecting the effect of isothermal surfaces, the ellipticity of the surface of the perfect fluid may be generally expressed thus,

$$e_1 = m_1\Phi(a_1) \pm m\Psi(a_1, a'),$$

the double sign being placed before $m\Psi(a_1a')$ to show that, according as the ellipticity of the shell's inner surface is greater or less than that of its outer surface, this term should be added or subtracted, as must appear from the theory of the attraction of spheroids. If, when e_1 is supposed to increase, the small term alluded to be neglected, the truth of any conclusion as to the rapid increase of e_1 deduced from an examination of the remaining term will be only rendered still more manifest.

Let at any period of the shell's existence the surface of the nucleus be supposed to coincide with the shell's inner surface, then $m_1 = m$, and consequently, from the expressions given in art. 6, we may deduce

$$e_1 = \frac{e_1 m a_1^3 \int_0^{a'} \varrho_2 a^2 da'}{2\left\{e_1 \int_0^{a_1} \varrho_2 a^2 da - \frac{1}{5a^2}\int \varrho . da^5 e_1\right\}} = \frac{m a_1^3 \int_0^{a'} \varrho_2 a^2 da}{2\left(1-\frac{3}{5\sigma_2}\right)\int_0^{a_1} \varrho_2 a^2 da - \frac{2e_1}{5a_1^2}\int_0^{a_1} \varrho a_1^5 da} = \frac{m a_1^3}{2\mu\left(1-\frac{3}{5\sigma_2}\right)},$$

σ_2 being a number depending on the law of density of the nucleus, and analogous to σ of article 5. But as the centrifugal force at the surface of the spheroid is proportional to the square of its angular velocity, and as the angular velocity is inversely proportional to the moment of inertia of the mass, we shall have

$$m = m'\left(\frac{\mathrm{I}'}{\mathrm{I}}\right)^2,$$

I′ representing the moment of inertia of the mass in its state of entire fluidity, I the moment of inertia corresponding to m, and m' the value of m corresponding to I′. From the general expression for the moment of inertia of a spheroid, we can write

$$\frac{\mathrm{I}'}{\mathrm{I}} = \frac{\frac{a'^2}{\sigma_1'}}{\frac{a'^2}{\sigma} - \mu a_1^2\left(\frac{1}{\sigma_1} - \frac{1}{\sigma_2}\right)}$$

(σ_2' being the value of σ_2 when $a_1 = a'$).

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* Philosophical Transactions, 1842, p. 45.

Hence, making $a'=1$,

$$e_1=\frac{m'}{2}\left(\frac{\sigma}{\sigma'_2}\right)^2\left\{\frac{a_1^3}{\mu}+a_1^5\sigma\frac{(\sigma_2-\sigma_1)}{\sigma_1\sigma_2}\right\}^2\left(1-\frac{3}{5\sigma_1}\right)^{-1}=\frac{m'}{2}\left(\frac{\sigma}{\sigma'_2}\right)^2\left[\nu^2+2\nu a_1^5\sigma\frac{(\sigma_2-\sigma_1)}{\sigma_1\sigma_2}\right]\left(1-\frac{3}{5\sigma_1}\right)^{-1},$$

where ν^2 represents a number which always differs but little from 1. The coefficient of a_1^5 being small, it is evident that the numerator of this expression cannot vary rapidly with a_1.

From article 12, it is evident that e_1 must always either increase or decrease as a_1 increases; in order to know how it varies, it will therefore be only necessary to examine its value for any two values of a_1.

Let $a_1=1$, then

$$e_1=\frac{m'}{2}\left(\frac{\sigma}{\sigma'_2}\right)^2\left[1+2\frac{(\sigma'_2-\sigma)}{\sigma_2}\right]\left(1-\frac{3}{5\sigma}\right)^{-1}=\frac{9}{10}\,\frac{m}{(\sigma)^2}\mathrm{K},$$

(σ) being determined by observation, and K having the value assigned to it in art. 8, Part I. It will appear that the greatest value of K which can be assigned will make e a little less than $\frac{1}{300}$.

When $a_1=0$,

$$e'=\frac{5}{2}m\left(\frac{\sigma}{\sigma'_2}\right)^2\frac{\nu_1^2\sigma'_1}{5\sigma'_1-3},$$

σ'_1 and ν_1 being nearly equal to unity; and σ'_2 and σ not much differing, e' will not much differ from m, and consequently it will be greater than e. This remark can be verified by actual calculation, when we shall have obtained the numerical values of the quantities contained in the preceding expression.

V. THE PRINCIPAL MOMENTS OF INERTIA OF THE EARTH.

14. The dependence of all the phenomena of the earth's rotation upon its principal moments of inertia, and the resulting connexion which thus subsists between these phenomena and the internal constitution of the earth, renders a complete investigation of their values of some importance for the objects to be fulfilled by the present memoir.

Let the moment of inertia with respect to the axis of rotation be C, and A and B those for the other two axes. Let C_1, &c. represent the moments of inertia of the solidified spheroid included within the shell's outer surface, C_2, &c. the moments of inertia of the spheroid included within the shell's inner surface, and C_3, &c. the moments of inertia of the nucleus, then

$$C=C_1-C_2+C_3,\quad B=B_1-B_2+B_3,\quad A=A_1-A_2+A_3,$$

and representing an element of the earth's mass by dm,

$$C=\int(x^2+y^2)dm,\quad B=\int(x^2+z^2)dm,\quad A=\int(y^2+z^2)dm,$$

x, y, z being the rectangular coordinates of the element dm. In finding C_1, &c., C_2, &c., C_3, &c., different values for dm must in general be introduced in the foregoing expressions, and then the integrals may be taken between the limits proper for each particular case.

Let x, y and z be transformed into polar coordinates as in article 2, and the sums of their squares taken two and two be put in such a form as to satisfy the equation of LAPLACE's coefficients. We shall then have, putting μ for $\cos\theta$,

$$C_1=\int_{-1}^{+1}\int_0^{2\pi}\int_0^r \varrho_2 r^4\left\{\frac{2}{3}+\left(\frac{1}{3}-\mu^2\right)\right\}drd\omega d\mu,$$

$$B_1=\int_{-1}^{+1}\int_0^{2\pi}\int_0^r \varrho_2 r^4\left\{\frac{2}{3}+\left[\frac{1}{3}-(1-\mu^2)\sin^2\omega\right]\right\}drd\omega d\mu,$$

$$A_1=\int_{-1}^{+1}\int_0^{2\pi}\int_0^r \varrho_2 r^4\left\{\frac{2}{3}+\left[\frac{1}{3}-(1-\mu^2)\cos^2\omega\right]\right\}drd\omega d\mu.$$

But

$$\int_0^r \varrho_2 r^4 dr=\frac{1}{5}\int_0^{a'}\varrho_2\frac{d(r^5)}{da}da=\frac{1}{5}\int_0^{a'}\varrho_2\frac{d}{da}[a^5(1+\beta\omega)]da,$$

and

$$W=W_0+W_1+W_2+\ldots.+W_i.$$

From article 5 $W_i=0$, except when $i=2$ or 1; and in the latter case it is made to disappear when a' is the radius of a sphere equal in volume to the spheroid; we have, therefore, on making

$$\int_0^{a'}\varrho_2\frac{d(a^5)}{da}da=\chi(a'),$$

and

$$\int_0^r \varrho r^4 dr=\frac{1}{5}\chi(a')+\int_0^{a'}\varrho_2 d\frac{(a^5\beta W_2)da}{da}=\frac{1}{5}\chi(a)-5m\left[f(a')\int_0^a\varrho_2 a^2 da-\frac{1}{2}\int_0^{a'}\varrho_2 a^2 da\right]\left(\frac{1}{3}-\mu^2\right)$$

by article 5. Consequently

$$\left.\begin{aligned}C_1&=\frac{4}{3}\left[\frac{2\pi}{5}\chi(a')-\frac{Mm}{3}\left(f(a')-\frac{1}{2}\right)\right],\\ C_2&=\frac{4}{3}\left[\frac{2\pi}{5}\chi(a_1)-\frac{Mm}{3}\left(f(a_1)\mu_1-\frac{1}{2}a_1^5\right)\right],\\ C_3&=\frac{4}{3}\left[\frac{2\pi}{5}\chi_1(a_1)-\frac{Mm}{3}\left(e_1a_1^2\mu_1-\frac{1}{2}m_1a_1^5\right)\pm ma_1^5\Psi(a_1,a')\right],\end{aligned}\right\}\quad\ldots\ldots\quad(30.)$$

where

$$\chi_1(a_1)=\int_0^{a_1}\varrho\frac{d(a^5)da}{da}.$$

Hence

$$C=\frac{4}{3}\left\{S+\frac{M\Psi}{3}\right\},\quad\ldots\ldots\ldots\ldots\ldots\ldots\quad(31.)$$

making for brevity

$$S=\frac{2\pi}{5}[\chi(a')-\chi(a_1)+\chi_1(a_1),\quad\ldots\ldots\ldots\ldots\quad(32.)$$

$$\Psi=e_1\mu_1a_1^2-\frac{1}{2}m_2a_1^5-m\Big[\frac{1}{2}-f(a')+\mu_1a_1^2f(a_1)-\Big(\frac{1}{2}+\Psi(a_1,a')a_1^5\Big]\quad..\quad(33.)$$

By following a similar process we obtain

$$\mathrm{A}=\frac{4}{3}\left\{\mathrm{S}-\frac{\mathrm{M}\Psi}{6}\right\},\ \mathrm{B}=\frac{4}{3}\left\{\mathrm{S}-\frac{\mathrm{M}\Psi}{6}\right\},$$

and consequently

$$\frac{2\mathrm{C}-\mathrm{A}-\mathrm{B}}{\mathrm{C}}=\frac{\Psi}{\mathrm{S}}\mathrm{M},$$

neglecting quantities of the second order.

On substituting for ϱ_2 its value (art. 9.),

$$\chi(a')-\chi(a_1)=\frac{5\mathrm{C}_2}{n_2^4}\{[2n_2^2+(n_2^2-6)q_2]\sin n_2-[2a_1^2n_2^2+(a_1^2n_2^2-6)q^3]\sin a_1n_2\};$$

and similarly, on substituting for ϱ its value in $\chi_1(a_1)$,

$$\chi_1(a_1)=\frac{5a_1\varrho_2k}{n_1^4}[2a_1^2n_1^2+(a_1^2n_1^2-6)q_1];$$

but by articles 8. and 9,

$$\mathrm{C}_2=\frac{(\varrho_2)}{\sin n_2},\quad \varrho_2=(\varrho_2)\frac{\sin a_1n_2}{\sin n_2},\quad \mathrm{M}=4\pi(\varrho_2)q_2n_2^2,$$

(ϱ_2) being the value of ϱ_2 at the shell's outer surface. Hence, finally,

$$\mathrm{S}=\frac{\mathrm{M}}{2q_2}\left\{\left[2+\left(1-\frac{6}{n_2^2}\right)q_2\right]-\left[2a_1^2+\left(a_1^2-\frac{6}{n_2^2}\right)q_3\right]\frac{\sin a_1n_2}{\sin n_2}\right.$$
$$\left.+\left[2a_1^2+\left(a_1^2-\frac{6}{n_1^2}\right)q_1\right]\frac{kn_2^2\sin a_1n_2}{n_1^2\sin n_2}\right\}.$$

But we have, by article 9,

$$k=\frac{n_1^2}{n_2^2}\frac{q_3}{q_1};$$

and on comparing equations (20.) and (23.),

$$\Psi=\frac{2e+m-\lambda}{3}; \qquad \text{(34.)}$$

hence if we make

$$\frac{2\mathrm{C}-\mathrm{A}-\mathrm{B}}{\mathrm{C}}=p',$$

we shall obtain

$$\left\{2a_1^2+\left(a_1^2-\frac{6}{n_2^2}\right)q_3-\frac{q_3}{q_1}\left[2a_1^2+\left(a_1^2-\frac{6}{n_1^2}\right)q_1\right]\right\}\sin a_1n_2=\mathrm{Q},$$

or

$$\left\{2a_1^2\left(1-\frac{q_3}{q_1}\right)-6\left(\frac{1}{n_2^2}-\frac{a_1^2}{n'^2}\right)q_3\right\}\sin a_1n_2=\mathrm{Q}, \qquad \text{(35.)}$$

making for brevity

$$\mathrm{Q}=\left[2+\left(1-\frac{6}{n_2^2}\right)q_2-\frac{2}{3}\cdot\frac{2e+m-\lambda}{p'}q_2\right]\sin n_2. \qquad \text{(36.)}$$

But the value of p' is given from the phenomena of the precession of the equinoxes and the nutation of the earth's axis, and that of λ may be obtained from experiments made with the pendulum on the earth's surface, or from the inequalities in the moon's motion in longitude and latitude depending upon the form and internal constitution of the earth. Thus an expression for finding a_1 has been obtained in which e_1 is absent, the elimination having been effected between the expressions depending on the variation of gravity at the earth's surface and the precessional phenomena.

As $C-A=C-B=\frac{2}{3}M\Psi$, it follows that the difference of the principal moments of inertia of the earth is proportional to Ψ. But from the general expression for Ψ and from Section IV., it is evident that Ψ increases as a_1 diminishes, hence we may in general conclude that *the difference between the greatest and least moment of inertia of the earth increases as the thickness of the shell increases.* This conclusion being independent of any knowledge of the absolute laws of density of the earth's interior, deserves particular attention.

VI. ON THE EXISTENCE OF A SOLID NUCLEUS WITHIN THE EARTH.

15. In the preceding investigations the earth has been supposed to solidify solely from its surface towards its centre, but it is possible to conceive how from the enormous pressure on its central strata solidification could also proceed from the centre towards the surface. If the influence of pressure in promoting solidification were sufficiently great, the earth might have solidified entirely from its centre towards its surface, according to the theory proposed by Poisson. It becomes important therefore to examine how far we are justified in adopting the theory of solidification first mentioned.

If solidification took place from the centre towards the surface alone, we should believe the earth to be now entirely solid. The forms of the solid strata, composing the spheroid in this case, would not be in general the same as if the original fluid mass had solidified from its surface towards its centre. Before the solidification of any part of the mass, it would consist, in virtue of hydrostatical laws, of a series of spheroidal strata of equal pressure. Refrigeration at the centre would proceed at an almost insensible rate from the impediments to convection adduced in article 6, Part I., and from the necessarily slow conducting power of the fluid; and the theory of solidification examined requiring the predominance of pressure over refrigeration as an agent in solidifying the mass, it must follow that the forms of the isothermal surfaces would have little influence on those of the solidified strata. For greater simplicity, I abstract, in the first instance, the effects of refrigeration in contracting the solid nucleus and the surrounding fluid.

The first small nucleus solidified would evidently be bounded by the surface of equal pressure due to its radius. No change can take place therefore in the direction of the resultant of the forces acting on any molecule of the stratum in contact with the solid nucleus, and hence on solidifying it will retain its form. The next stratum must become solid, similarly, without changing its form, and so on towards the surface. Hence the ellipticities of the strata of the solid spheroid would be the same as when it existed in a fluid state.

If the effect of refrigeration in contracting the matter of the entire spheroid be now considered, it is evident that it will tend to lessen the mean radius of the entire mass, and consequently to increase its angular velocity of rotation. The ellipticities of the strata of fluid surrounding the nucleus would be greater after every new addition to its mass than they were before that addition took place, and therefore, after the complete solidification of the entire mass, its strata would increase in ellipticity from its centre to its surface more rapidly than the strata of the original fluid mass increased in ellipticity. In this case, the variation of gravity at the surface of the earth in going from its equator to its poles, should, by the theory of the attraction of spheroids, be greater than for the same mass in a fluid state with the same ellipticity at surface. Observation however shows that, on the contrary, the variation of gravity at the earth's surface is less rapid than for the primitively fluid spheroid. The earth could not therefore have solidified in this manner required by this theory.

16. If, by the action of refrigeration and compression, solidification proceeded simultaneously from the surface towards the centre, and from the centre towards the surface, it will not be doubted but that the former process, when once commenced, must proceed far more rapidly than the latter. The temperature at the centre would be nearly constant, compared with the temperature of the surface of the fluid, from the obstacles opposed to convection and the laws of propagation of heat by conduction. Solidification at the centre will therefore be due chiefly to pressure; but if contraction accompany the change of state of the fluid matter in becoming solid, it appears from Section III. that the pressure on every stratum of the fluid will decrease with the radius of the shell's inner surface. The pressure on the solid nucleus will thus be continually diminishing, while its temperature will remain almost unchanged. The solid nucleus would therefore, instead of acquiring increased magnitude, tend to return to its original fluid state. This will evidently be true at every period of the existence of the nucleus, and hence we must conclude that this mode of solidification is incompatible with our original assumptions.

VII. THE DIRECTIONS OF THE FISSURES IN THE SHELL WHICH MIGHT BE PRODUCED BY THE ACTION OF THE PRESSURES CONSIDERED IN SECTION I.

17. If the pressure of the nucleus against any part of the shell be sufficiently intense to produce a fissure, the direction of that fissure will depend on those of the tensions resulting from the fluid pressure and on the physical structure of the shell. In the actual case of the earth it is probable that the highly crystalline structure, which we have reason to believe is characteristic of the shell, would give to some portions of it a tendency to fracture in particular directions. We have at present no precise physical reasons for thinking that this tendency should follow any general law, so that it must now be considered as only a source of irregular deviations in the directions of the fissures from those which they would have if the shell possessed an uniform cohesive strength.

Abstracting these irregular causes, an examination of the question of the directions of the fissures in a spheroidal and nearly spherical shell, composed of strata each possessing in itself an uniform cohesive strength, but differing in this respect from every other, would assist in pointing out what should be the predominant directions of the fissures, if the greater effectiveness of general over particular causes be allowed.

The problem which is here to be examined is therefore simply to find the directions of the fissures in a thin, solid and nearly spherical shell, resulting from the pressures of a mass of fluid inclosed in it, the cohesion of the shell being supposed to vary, according to some continuous law, along a vertical line from its inner to its outer surface.

If the constant pressure referred to in Section I. alone acted on the shell, the tensions at any point in one of the shell's indefinitely thin strata would be equal to each other and situated in the tangent plane at that point. The position of the maximum resultant tension would therefore be indeterminate, and consequently there would be no tendency to form a fissure in any particular direction rather than in any other. If the variable pressure be superimposed on the constant pressure, the direction of the maximum resultant tension would be determinate, and consequently also the line in which a fissure would commence. At first, if the intensity of the pressures should gradually increase, a portion of the shell at each side of the equator bounded by parallels would be subjected to tensions sufficiently great to produce fissures, while beyond these parallels the shell would remain unfractured. The portion where the tensions would be sufficiently great to produce fissures, would thus constitute a disturbed district with nearly fixed boundaries. At a point where there is a tendency towards the formation of a fissure, the direction of the maximum resultant tension will be in the direction of the tangent to the meridian; the greatest tendency to form a fissure will therefore be parallel to the equator. From the nature of the variable pressure the maximum tensions must be equal, at equal distances from the equator; hence such a fissure, when once commenced, would tend to be propagated along a parallel of latitude until the force of the tensions become sufficiently lessened by the separation of the extended portion of the shell. Similar fissures would be formed simultaneously and symmetrically at each side of the equator. As long as the tensions in the directions of the tangents to the meridians continued sufficiently great, such fissures would be formed; but, as already mentioned, their formation would tend to annul these tensions, and a new system would result, having a tendency, as may be readily deduced from Mr. Hopkins's investigations[*], to produce fissures perpendicular to those previously formed. If the maximum intensity of the variable pressure be not inconsiderable compared to the constant pressure, it will follow, if the pressures continue to act with sufficient energy, that all the shell's fissures will be either parallel or perpendicular to the equator.

If, on the contrary, the constant pressure were far greater than the variable pressure, the maximum and minimum resultant tensions would be nearly equal, and consequently the directions of the fissures would be governed chiefly by accidental causes. Taking into consideration the causes which have been abstracted, it appears therefore that the directions of the fissures might in general have no necessary relations with that of the equator. If such a fissure commenced forming in the direction of any great circle, it would evidently continue to be propagated in the same general direction unless accidental causes should alter its course.

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[*] Cambridge Philosophical Transactions, vol. vi.

At some stages of the shell's existence the relation between the variable and the constant pressure might be such as to cause the maximum tension at any point to be in the direction of the tangent of the meridian, or parallel at that point, and hence, in this case at least, all simultaneously formed fissures should be parallel; the term parallel being used to mean that the tangents to the circles forming the prolongations of these fissures should all form equal angles at the points of intersection with the tangents of a great circle bisecting them.

VIII. ON THE EXISTENCE OF A ZONE OF LEAST DISTURBANCE IN THE SHELL.

18. During the process of the formation of the shell, the forces tending to fracture it, and those holding its parts together, will in general be continually varying. If the intensity of the former class of forces increased much more rapidly than that of the latter, there would be no limit to the disturbed part of the shell; if, on the contrary, the latter class of forces increased more rapidly in intensity than the former, some parts of the shell might after a certain time be comparatively undisturbed. It is even possible to conceive, if the constant pressure of the fluid against the shell be small, that in some parts of the shell the cohesive forces keeping its particles together might be always greater than the rupturing forces at these parts.

In order to form a general idea of the positions of such undisturbed portions of the shell, the variation of the effective pressure at any point in the shell must be considered. Of the two different ways in which the effective pressure could vary in going from the equator to the pole of the shell, it is evident, from Section IV., that the only one which it is necessary to consider is that of its decrease. In this case we may conclude, from article 2, that the pressure everywhere between the equator and parallel of mean pressure must be greater than that which exists at the same parallel, and that everywhere between this line and the pole the pressure will on the contrary be less. The disturbed portion of the shell must therefore be near the equator, and that line must divide it into two equal parts. In order that an undisturbed zone of the shell may exist, it is not necessary that the latter should be perfectly rigid; it may be capable of subsiding by the abstraction of a certain amount of the pressure of the fluid until its parts should rest in equilibrium. With a considerable variable pressure and a constant pressure insufficient to produce fractures in the shell, it is possible to conceive how this could occur, and hence the most general idea which can be formed of the undisturbed portion of the shell at either side of the equator, is that it must be a zone bounded by two parallels, both of which may become coincident with the equator, or evanescent, according as the pressures are very small or very great. If it be admitted that any great disturbances in the shell must have been chiefly due to the action of such pressures, it would be useful to examine the problem of the determination of the boundaries of the zone of least disturbance. By comparing the results of our investigation with observed phenomena, we may be able to deduce some conclusions directly applicable to geology.

I proceed therefore to determine the analytical expressions for the latitude of the limiting parallel of rupture on the side of the zone nearest to the equator. Let θ_2 represent this latitude, θ_3 the latitude of a parallel in the supposed undisturbed part of the shell.

It will appear that the general equation between the rupturing and cohesive forces upon which the position of the parallel of mean pressure depends, can, when the influence of temperature is abstracted, be made to contain but two independent variables θ_2 and a_1, or that it will be of the form $F(\theta_2, a_1)=0$. The value required of θ_2 must evidently be a maximum, and hence we must determine it in general by elimination between the equations

$$F(\theta_2, a_1), \quad \frac{dF}{da_1}+\frac{dF}{d\theta_2}\frac{d\theta_2}{da_1}=0, \quad \text{or} \quad \frac{dF}{da_1}=0;$$

the fact of the resulting value being a maximum or minimum can be determined as usual by the sign of $\frac{d^2\theta}{da_1^2}$.

19. Let two infinite planes be conceived to pass through the axis of rotation of the shell, making so small an angle with each other that the curvature of the arc of the equator intercepted between them could be considered as insensible. The ratio of the rupturing to the cohesive forces in either of the opposite portions of the shell thus intercepted, will be the same as for the whole shell under our assumed conditions. The conditions for finding the section of rupture of one of these bands will therefore be the same as those for the entire shell.

Let dL represent an element of the area of the section of rupture, l its perpendicular distance from the neutral surface, l_1 and l_2 the perpendicular distances of the neutral surface from the outer and inner surfaces of the shell, s the resistance measured by the number of units of force required to rupture a square unit of section of the material of the shell at the distance l. The meaning generally attached, in works on mechanics, to the term neutral surface, is that here attached to it, namely, the surface at which the portions of the band subjected to the rupturing forces are neither compressed nor extended.

Let, as is generally assumed, s be a function of l, and let s_1 be its value at the distance l_1.

If the deflection of the band, in a state of tension and bordering on rupture, be very small, as must undoubtedly be the case from its physical structure, the directions of the rupturing forces will be perpendicular to the neutral surface, and therefore, from a well-known property of that surface, l_1 and l_2 will be the perpendicular distances of the centre of gravity of the section of rupture, from the outer and inner surfaces of the shell.

The force developed upon the element $d\mathrm{L}$, opposed to the compression or extension of the material of the band at the distance l_1, will be $\frac{sl}{l_1}d\mathrm{L}$, and its moment about the line formed by the intersection of the neutral surface with the section of rupture will be $\frac{s}{l_1}l^2d\mathrm{L}$.

Let r_2 represent the radius drawn from the centre of the spheroid to the intersection of the neutral surface with the section of rupture; then the moment of the pressure P_1 between the section of rupture and the parallel of θ will be $r_2\mathrm{P}\sin(\theta-\theta_2)d\mathrm{L}'$, where θ stands for the latitude at any point of the band subjected to tension, and $d\mathrm{L}'$ an element of the area of the shell's inner surface. If we represent by b_1 the equatorial axis of the shell's inner surface, ω_1 the arc intercepted between the planes bounding the band, b_2 the equatorial axis of the neutral surface, and make $\varepsilon^2=\frac{b_1^2-a_1^2}{a_{{}_{\prime}}^2}$, we shall have

$$d\mathrm{L}=\frac{\omega_1 b_1\cos\theta}{1-\varepsilon^2\sin^2\theta},\quad r=b_2\sqrt{1-\varepsilon^2\sin^2\theta}.$$

As the sum of the moments of the pressures exerted on the band at either side of the section of rupture, when the shell is in the state bordering on rupture, must be equal to the sum of the moments of the cohesive forces at the same section, we shall have

$$\frac{1}{l_1}\int sl^2d\mathrm{L}=\int_{\theta_2}^{\theta_3}r_2\mathrm{P}_1\sin(\theta-\theta_2)d\mathrm{L}=\omega b_1^2b_2(1-\varepsilon^2)\int_{\theta_2}^{\theta_3}\frac{\mathrm{P}_1\sin(\theta-\theta_2)\cos\theta d\theta}{(1-\varepsilon^2\sin^2\theta)\frac{3}{2}}.$$

But from article 3, $\mathrm{P}_1=h(h_1+\cos^2\theta)$, making for brevity

$$h=(f-f_1)\int_0^{a'}\varrho a da,\quad h_1=\frac{\Pi}{h}-\frac{2}{3},$$

and remembering that here $\frac{\pi}{2}-\theta$ of that article is represented by θ. Hence

$$\frac{\int sl^2d\mathrm{L}}{l_1\omega_1b_1^2b_2(1-\varepsilon^2)h}=\int_{\theta_2}^{\theta_3}\frac{(h_1+\cos^2\theta)\sin(\theta-\theta_2)\cos\theta d\theta}{(1-\varepsilon^2\sin^2\theta)\sqrt{1-\varepsilon^2\sin^2\theta}}$$

$$=h_1\cos\theta_2\int\cos\theta\sin\theta(1-\varepsilon^2\sin^2\theta)^{-\frac{3}{2}}d\theta-h_1\sin\theta_2\int\cos^2\theta(1-\varepsilon^2\sin^2\theta)^{-\frac{3}{2}}d\theta$$

$$+\cos\theta_2\int^{\theta}\cos^3\theta\sin\theta(1-\varepsilon^2\sin^2\theta)^{-\frac{3}{2}}d\theta-\sin\theta_2\int\cos^4\theta(1-\varepsilon^2\sin^2\theta)^{-\frac{3}{2}}d\theta.$$

The integrals multiplied by $\cos\theta_2$ can be easily found by ordinary methods, but the two multiplied by $\sin\theta_2$ cannot be given in a finite form. But from the nature of the problem one of the limits at least of the integrals must be an independent variable; hence the integrals multiplied by $\sin\theta_2$ can be determined only by developing the irrational factor in a converging series, and then integrating separately the resulting terms. For greater uniformity I develope in all the integrals the irrational factor, which becomes when developed

$$1+\frac{3}{2}\varepsilon^2\sin^2\theta+\frac{3}{2}\cdot\frac{5}{4}\varepsilon^4\sin^4\theta+\frac{3}{2}\cdot\frac{5}{4}\cdot\frac{7}{6}\varepsilon^6\sin^6\theta+\text{ etc.}$$

Hence the sum of the four integrals will be, neglecting terms of the order ε^4,

$$h_1\left[\cos\theta_2\int\cos\theta\sin\theta d\theta-\sin\theta_2\int\cos^2\theta d\theta\right]+\cos\theta_2\int\cos^3\theta\sin\theta d\theta-\sin\theta_2\int\cos^4\theta d\theta$$

$$-\frac{3}{2}\varepsilon^2\{h_1\left[\cos\theta_2\int\sin^3\theta\cos\theta d\theta-\sin\theta_2\int\cos^2\theta\sin^2\theta d\theta\right]+\cos\theta_2\int\cos^3\theta\sin^3\theta d\theta-\sin\theta_2\int\cos^4\theta \sin$$

On taking these integrals between the limits θ_2 and θ_3, the expression becomes

$$\begin{aligned}&h_1\left[\frac{\cos\theta_2}{4}(\cos 2\theta_2-\cos 2\theta_3)-\frac{\sin\theta_2}{2}\left[\frac{1}{2}(\sin 2\theta_3-\sin 2\theta_2)+\theta_3-\theta_2\right]\right]+\frac{\cos\theta_2}{8}\left[\frac{1}{4}(\cos 4\theta_2-\cos\theta_3+\cos 2\theta_2-\cos 2\theta_3\right]\\&-\frac{\sin\theta_2}{4}\left[\frac{1}{3}(\sin 4\theta_3-\sin 4\theta_2)+\sin 2\theta_3-\sin 2\theta_2+\frac{3}{2}(\theta_2-\theta_3)\right]-\frac{3}{2}\varepsilon^2\left\{h_1\frac{\cos\theta_2}{8}\left[\frac{1}{4}(\cos 4\theta_3-\cos 4\theta_2)\right.\right.\\&\left.-(\cos 2\theta_3-\cos 2\theta_2)\right]+\frac{h_1\sin\theta_2}{8}\left[\frac{1}{4}(\sin 4\theta_3-\sin 4\theta_2)-\theta_3+\theta_2\right]+\frac{\cos\theta_2}{64}\left[\frac{1}{3}(\cos 6\theta_3-\cos 6\theta_2)\right.\\&\left.\left.-3(\cos 2\theta_3-\cos 2\theta_2)\right]+\frac{\sin\theta_2}{32}\left[\frac{1}{6}(\sin 6\theta_3-\sin 6\theta_2)+\frac{1}{2}(\sin 4\theta_3-\sin 4\theta_2)-\frac{1}{2}(\sin 2\theta_3-\sin 2\theta_2)-2(\theta_3-\theta_2)\right]\right\}\end{aligned}$$

$$\left.\begin{aligned}&=[(a_1)\sin(\theta_3+\theta_2)\sin(\theta_3-\theta_2)+(a_2)\sin 2(\theta_3+\theta_2)\sin 2(\theta_3-\theta_2)+(a_3)\sin 3(\theta_3+\theta_2)\sin 3(\theta_3-\theta_2)]\cos\theta_2\\&-[(b_1)\cos(\theta_3+\theta_2)\sin(\theta_3-\theta_2)+(b_2)\cos 2(\theta_3+\theta_2)\sin 2(\theta_3-\theta_2)+(b_3)\cos 3(\theta_3+\theta_2)\sin 3(\theta_3-\theta_2)]\sin\theta_2\\&-(c_1)(\theta_3-\theta_2)\sin\theta_2.\end{aligned}\right\}.$$

Making for brevity

$$\left.\begin{aligned}&(a_1)=\frac{1}{2}\left[h_1+\frac{1}{2}-\frac{3}{8}\varepsilon^2\left(h_1+\frac{3}{8}\right)\right],\quad a_3=\frac{1}{16}\left(1-\frac{3}{2}\varepsilon^2h_1\right),\quad a_3=\frac{\varepsilon^2}{64},\\&(b_1)=\frac{1}{2}\left[h_1+1-\frac{3\varepsilon^2}{32}\right]\qquad (b_2)=\frac{1}{16}\left[1+\frac{3}{2}\varepsilon^2\left(h_1+\frac{1}{2}\right)\right],\quad b_3=(a_3),\\&\qquad\qquad (c_1)=\frac{1}{2}\left[h_1+\frac{3}{4}+\frac{3}{8}\varepsilon^2\left(h_1+\frac{1}{2}\right)\right].\end{aligned}\right\}\quad .\ .\ .\quad (38.)$$

20. I now proceed to determine the expressions for $\int sl^2d\mathrm{L}$. In general the cohesive strength of an unit of surface of the section of rupture may be considered proportional to the number of molecules of which it is the section, and as the density ϱ_2 must at any point be also proportional to the number of molecules at that point, it follows that

$$s=s_1\frac{\varrho_2}{(\varrho_2)}.$$

The section of rupture may evidently be considered as a trapezoid, hence

$$d\mathrm{L}=\frac{\omega_1}{r_1}(r_2+l)\cos\theta_2 dl=\frac{\omega_1}{a_1}(1-\varepsilon^2\cos^2\theta)\cos\theta_2(a_1+l_2+l)dl=\frac{\omega_1}{a_1}(a_1+l_2+l)\cos\theta_2 dl$$

very nearly. Hence

$$\int sl^2d\mathrm{L}=\frac{\omega_1 s_1\cos\theta_2}{a_1\varrho_2}\int_{-l_2}^{+l_1}\varrho_2(a_1+l_2+l)l^2dl.$$

Let v represent the distance from the centre of the spheroid of any element of the section of rupture, v_1 the distance of the centre of gravity of that section, then

$$l_1=1-v_1,\ l_2=v_1-a_1,\ v_1=\frac{\int_{a_1}^{1}\varrho_2 v^2 dv}{\int_0^{1}\varrho_2 v dv}\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ \text{(39.)}$$

But $\varrho_2=\frac{C_2\sin a_1n_2}{a_1}$ (art. 9.) at the distance a_1; hence, substituting its value for the distance a_1+l_2+l, we obtain

$$\int\varrho_2(a_1+l_2+l)l^2dl=C_2\int l^2\sin(a_1+l_2+l)n_2dl.$$

Let $a_1+l_2+l=u$, and the preceding factor of C_2 becomes

$$\int u^2\sin un_2du-2(a_1+l_2)\int u\sin un_2du+(a_1+l_2)^2\int\sin un_2du.$$

Integrating between the limits l_1 and l_2, and we have

$$\int u^2\sin un_2du=\frac{1}{n_2^3}\{n_2^2a_1^2\cos a_1n_2-n_2^2(a_1+l_1+l_2)\cos(a_1+l_1+l_2)n_2$$

$$+2(a_1+l_2+l_2)n_2\sin(a_1+l_1+l_2)n_2-2a_1n_2\sin a_1n_2+2\cos(a_1+l_1+l_2)n_2-2\cos a_1n_2\},$$

$$\int u\sin un_2du=\frac{1}{n_2^2}[(a_1+l_1+l_2)n_2\cos(a_1+l_1+l_2)n_2+a_1n_2\cos a_1n_2+\sin(a_1+l_1+l_2)n_2-\sin a_1n_2],$$

$$\int\sin un_2du=\frac{1}{n_2}[\cos a_1n_2-\cos(a_1+l_1+l_2)n_2].$$

But $l_1+l_2=1-a_1$; hence

$$\int_{-l_2}^{+l_1}\varrho_2(a_1+l_2+l)l^2dl=C_2\Big\{\frac{1}{n_2^3}[(n_2^2a_1^2-2)\cos a_1n_2-(n_2^2-2)\cos n_2+2n_2(\sin n_2-u_1\sin a_1n_2)]\quad\text{(40.)}$$

$$+\frac{2(a_1+l_2)}{n_2^2}[\sin a_1n_2-a_1n_2\cos a_1n_2-\sin n_2+n_2\cos n_2]+\frac{(a_1+l_2)^2}{n_2}(\cos a_1n_2-\cos n_2)\Big\}.$$

To determine l_1 and l_2, I substitute for ϱ_2 its value in (39.) and integrate, then

$$v_1=\frac{n_2(a_1\cos n_2a_1-\cos n_2)+\sin n_2-\sin a_1n_2}{n_2(\cos a_1n_2-\cos n_2)}$$

$$l_1=\frac{(1-a_1)\cos a_1n_2}{2\sin\frac{1}{2}(1+a_1)n_2.\sin\frac{1}{2}(1-a_1)n_2}-\frac{1}{n_2}\cot\frac{1}{2}(1+a_1)n_2$$

$$l_2=\frac{1}{n_2}\cot\frac{1}{2}(1+a_1)n_2-\frac{(1-a_1)\cos n_2}{2\sin\frac{1}{2}(1+a_1)n_2.\sin\frac{1}{2}(1-a_1)n_2}.$$

If we make

$$j=\Big\{(1-a_1)\cot\frac{1}{2}(1-a_1)n_2-1\Big\}\cot\frac{1}{2}(1+a_1)n_2,$$

we shall have

$$l_1=\frac{1-a_1+j_2}{2},\ l_2=\frac{1-a_1-j_2}{2}.\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ \text{(41.)}$$

It appears, from the value of n_2 deduced by observation, that when $1-a_1$ is a small fraction, j will be small compared with l_1 or l_2; hence in general, when the shell is thin,

$$l_1=l_2=\frac{1}{2}(1-a)_1.$$

21. The function in which θ_2 is to be made a minimum is by art. 19,

$$\begin{aligned}(\mathrm{A})-[(a_1)\sin(\theta_3+\theta_2)\sin(\theta_3-\theta_2)+(a_2)\sin 2(\theta_3+\theta_2)\sin 2(\theta_3-\theta_2)+(a_3)\sin 3(\theta_3+\theta_2)\sin 3(\theta_3-\theta_2)]\\ +[(b_1)\cos(\theta_3+\theta_2)\sin(\theta_3-\theta_2)+(b_2)\cos 2(\theta_3+\theta_2)\sin 2(\theta_3-\theta_2)+(b_3)\cos 3(\theta_3+\theta_2)\sin 3(\theta_3-\theta_2)]\tan\theta_2\\ +(c_1)(\theta_3-\theta_2)\tan\theta_2=0\ [(\mathrm{A})\text{ being a function of }a_1],\end{aligned}$$

or

$$\begin{aligned}(\mathrm{A})-[(a_1)\sin(\theta_3+\theta_2)-(b_1)\cos(\theta_3+\theta_2)\tan\theta_2]\sin(\theta_3-\theta_2)-[(a_2)\sin 2(\theta_3+\theta_2)-(b_2)\cos 2(\theta_3+\theta_2)\tan\theta_2]\sin 2\\ -(a_3)[\sin 3(\theta_3+\theta_2)-\cos 3(\theta_3+\theta_2)\tan\theta_2]+(c_1)(\theta_3-\theta_2)\tan\theta_2=0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 42.)\end{aligned}$$

From this expression we can deduce the following conclusions:—

1st. If θ_2 be less than $\frac{\pi}{2}$, θ_3 cannot be zero unless $(\mathrm{A})=0$.

2nd. If $\theta_2=\frac{\pi}{2}=\theta_3$, $\cos(\theta_3+\theta_2)=-1$, $\cos 2(\theta_3+\theta_2)=0$, $\cos 3(\theta_3+\theta_2)=-1$,

and consequently

$$(\mathrm{A})=(b_1)+(b_3)-(c_1)=\frac{1}{8}\left[1-\frac{3}{2}\varepsilon^2\left(\frac{1}{2}+h_1\right)\right]$$

$$h_1=\frac{2}{\varepsilon^2}(1-8(\mathrm{A}))-\frac{1}{2}.$$

3rd. In order that in this case $\Pi=h$, we must have $(\mathrm{A})=\frac{1}{8}\left(1-\frac{5}{12}\varepsilon^2\right)$.

From article 20,

$$(\mathrm{A})=\frac{4s_1\int_0^{\frac{1}{2}(1-a_1)}\varrho_2(1+a_1+2l)l^2dl}{(1-2e_1)(1+e_1)^2(1-a_1^2)a_1^2h}.$$

The value obtained for the numerator of this expression, shows that for no conceivable value of a_1 (A) can vanish; and therefore from the first of the preceding conclusions, it may be deduced that if the shell be fixed under any parallel, it must be also fixed under some other parallel at the same side of the equator and at a distance from it, depending on the cohesive strength of the material of the shell. Consequently in the case of $\theta_2<\frac{\pi}{2}$ a zone of least disturbance should exist. In general it is evident that the value of (A) $\left(\text{supposing } \theta_3=\frac{\pi}{2}\right)$, which would make θ_2 a maximum, must be extremely small; consequently, from the second and third conclusions, if $\theta_2=\frac{\pi}{2}$, or if no zone of least disturbance exist, Π must be considerably greater than h.

IX. CALCULATION OF SOME OF THE CONSTANTS CONTAINED IN THE FORMULÆ OF THE PRECEDING SECTIONS.

22. 1st. To find the numerical value of n_2 and n. It is evident that when D represents the mean density of the earth, we should have

$$\frac{1}{n_2^2}(1-n_2\cot n_2)=\frac{D}{3(\varrho_2)},$$

(ϱ_2) being the density of the shell's outer surface, or in other words, the density of the first stratum solidified from the primitive fluid mass constituting the earth. To find D, I take a mean of the results of the best experiments which have been made for its determination, namely, of the experiments of Cavendish, Baily and Reich, or respectively of the numbers 5·48, 5·68 and 5·44. The mean of these results is 5·53 nearly. The density of granite, the crystalline rock which seems to form the base of all the sedimentary formations, is evidently that which must be used for $(\varrho_2.)$ This remark is important, because in all comparisons heretofore made of the mean and surface density of the earth, the mean density of the sedimentary rocks has been erroneously taken into consideration. From a comparison of the densities of granite obtained in different countries on the authority of different geological and engineering works, I have decided that the mean density of the rock cannot be less than 2·7. Adopting this value, the above equation becomes

$$\frac{1}{n_2^2}(1-n_2\cot n_2)=\cdot 682716,$$

which is approximately satisfied by making

$$n_2=\frac{14227}{18000}\pi=142^\circ\ 16'\ 22''.$$

To find n, we have

$$\frac{n^2}{1-n\cot n}=\frac{(k)n_2^2}{1-n_2\cot n_2}=\frac{(k)}{\cdot 682716}.$$

Let $(k)=\cdot 7481$, its least value found by experiment. Then

$$\log\left(\frac{n^2}{1-n\cot n}\right)=\cdot 0397196.$$

By trials I find that when $n=154^\circ\ 25'$, the quantity at the left side of the above expression is ·0396799, and when $n=154^\circ\ 24'$, it becomes ·0398333; hence it lies between both of these values.

When $n=154^\circ\ 24'\ 30''$,

$$\log\left(\frac{n^2}{1-n\cot n}\right)=\cdot 0397196,$$

hence this value will serve for a first approximation.

When $(k)=\cdot 896$, the greatest value found by experiment, we should have

$$\log\left(\frac{n^2}{1-n\cot n}\right)=\cdot 1180679.$$

The value $n=147^\circ\ 30'$ would make this ·1188293, hence this value of n would be a little too small.

2nd. To find p' and λ. From the fourth chapter of the fourth book of the work of M de Pontécoulant, it will be perceived that

$$p=\frac{4ln}{3m^2(1+\gamma)\cos h},$$

where l represents the mean movement of the equinoxes at the time when h represents the apparent obliquity of the ecliptic, and γ the ratio of the moon's action on the earth compared to that of the sun, n and m being constants, the former depending on the earth's rotation, and the latter on the sun's mean movement. If the variation of h be referred to the plane of the ecliptic in 1800,

$$h=23^\circ\ 27'\ 55'',\quad l=50''\cdot363541,$$

and also

$$n=360^\circ\cdot98561,\quad m=359^\circ\ 59'\cdot37\,;$$

and when m is referred to the same unit of time as n,

$$m=0^\circ\cdot98561.$$

Of the three different methods by which γ can be determined, I select that depending on the phenomena of nutation. I do so because it seems that astronomers have taken much pains to determine the numerical coefficient which depends on these phenomena, and on which the value of γ depends. If we represent the coefficient of nutation by N[*], we shall have

$$\frac{\gamma}{1+\gamma}=\frac{\mathrm{N}}{13''\cdot36926},\quad\text{or}\quad \gamma=\frac{\mathrm{N}}{13''\cdot36926-\mathrm{N}}.$$

The following values have been deduced for N

	″
By Robinson . . .	9·234
By Brinkley . . .	9·25
By Lindenau . . .	8·977
By Plana	8·925

the mean of which is 9″·0965, and therefore $\gamma=2\cdot128951$;

$$\begin{array}{rl}
\log(1+\gamma)= & \cdot4953988\\
\log m= & 6\cdot1125773\\
\log\cos h= & 9\cdot9625122\\
\log 3= & \cdot4771213\\
\hline
 & 7\cdot0476296
\end{array}
\qquad\qquad
\begin{array}{rl}
\log l= & 1\cdot7021163\\
\log\dfrac{n}{m}= & 2\cdot5637896\\
\log 4= & \cdot6020600\\
\hline
 & 4\cdot8679659\\
 & 7\cdot0476296\\
\hline
\log p'= & \bar{3}\cdot8203363
\end{array}$$

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[*] Pontécoulant, Théorie, &c., tome iv., Note 3, p. 654.

If we represent by λ' the coefficient of the variation of gravity at the earth's surface, found by pendulum experiments, and by λ'' the same coefficient deduced from observation of the moon's inequalities in longitude and latitude, then

$$\lambda'=\frac{5}{2}m-e', \quad \lambda''=\frac{5}{2}m-e'',$$

e' and e'' being the corresponding ellipticities of the earth's surface found by the ordinary theory. Let, in accordance with the latest calculations,

$$e'=\frac{1}{288}, \quad e''=\frac{1\text{[*]}}{300},$$

then λ, the most probable value of the coefficient of the variation of gravity, becomes

$$\frac{5}{2}m-\frac{1}{293\cdot88}.$$

3rd. To find the numerical value of Q in Section V. (equation 36). From the value of n_2 just obtained,

$$1-\frac{6}{n_2^2}=\cdot026872, \quad 2+\left(1-\frac{6}{n_2^2}\right)q_2=2\cdot11311.$$

If we make, in accordance with observation,

$$e=\frac{1}{300}, \quad m=\frac{1}{289},$$

and use the value of λ above obtained,

$$\frac{2}{3}\frac{2e+m-\lambda}{p'}q_2=\frac{8122.q_2}{5\times578\times2880p}=2\cdot07068,$$

$$Q=\cdot045253\times\sin n_2=\cdot0260259.$$

GEOLOGICAL DEDUCTIONS FROM THE FOREGOING INVESTIGATIONS.

(1.) *The Stability of the Axis of Rotation of the Earth.*

23. The conclusion arrived at in article 14, shows that if the rotation of the earth were originally stable about its axis, it would continue to rotate in the same way for ever.

The action of exterior bodies has been heretofore alone examined in considering the question of the position of the earth's axis of rotation within it. From this examination, it results that the action of such bodies would be incapable of producing any change in the position of the axis, and hence, if such a change were at all possible, it should be produced by some interior action by which the distribution of the particles composing the earth would be changed. It is admitted, that if the earth were fluid and in rotation with an angular velocity differing but little from its present angular velocity, it would rotate stably about its shorter axis. During the process of its successive solidification, it might happen that the new arrangements of the particles might be such as to disturb the rotation, not only by increasing or lessening the angular velocity, but also by changing the position of the axis. It appears however, from the article cited, that the difference of the greatest and least moment of inertia of the earth must progressively increase during the process of solidification, and hence that the stability of rotation must continually increase until it reaches its limit when the mass shall have arrived at the entirely solid state.

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[*] See HUMBOLDT's Kosmos, Bd. I. s. 174, and PONTÉCOULANT, tome iv. p. 486.

Thus not only does a question closely connected with geological theory seem to be definitively settled, but also the future stability of the earth's rotation appears to be completely assured.

(2.) *The Thickness of the Earth's Solid Crust.*

24. In Section II. expressions have been obtained in which the variation of gravity at the earth's surface is a function of the radius and ellipticity of the fluid nucleus supposed to exist within it, from which it will be possible to deduce the limiting values of that radius, and consequently of the thickness of the solid shell. If we refer to the general expression (20.), it will be perceived that the greater is e_1, the less the thickness of the shell; hence we would be able to obtain its greatest thickness consistent with observation, other quantities remaining unchanged, by giving to e_1 its least value. But from Section IV. the least value of e_1 is e, or the ellipticity of the surface of the shell, hence in this case $m_1=m$, and

$$\lambda=\left[\frac{5}{2}-3(f(a)-\mu_1 a_1^2 f(a_1)\right]m+2e-3\mu a_1^2 e.$$

The greatest value which a_1 can receive will depend on the limits imposed on the values of the functions depending on the earth's internal constitution; and if we give to these values favourable to a large value of a_1, e_1 must very nearly be equal to e. The above expression for λ will therefore suffice for this case by attributing the proper values to the functions $f(a)$ and $f(a_1)$. But when $e_1=e$, we have, by the expression deduced in article (5.),

$$\lambda=2e+m+\frac{3}{2}\left(\frac{5a_1^5\nu\sigma_1 m}{5\sigma_1-3}-2a_1^5\nu e-\frac{3m}{5\sigma-3}\right);$$

ν representing the same quantity as in article (13.), σ_1 will differ but little from σ when $e_1=e$, and with a continuous law of density of the strata of the shell; hence in a first approximation we may assume their equality. But $\lambda=\frac{5}{2}m-(e)$, (e) being the value of e, deduced by the ordinary theory from observation of the variation of gravity at the earth's surface, hence

$$a_1=\nu^{-\frac{1}{5}}\left[1-\frac{2}{3}\,\frac{(5\sigma-3)(e)-e\mathrm{I}}{6e-5\sigma(2e-m)}\right]^{\frac{1}{5}}.$$

To find the limiting values of a_1, we must make this a maximum or a minimum. If we suppose ν to differ but little from 1, it will be nearly constant, and therefore

$$\frac{da_1}{d\sigma}=\frac{2}{3}\left[1-\frac{2}{3}\,\frac{p\sigma-p'}{q'-q\sigma}\right]^{-\frac{4}{5}}\left[\frac{qp'-pq'}{(q-\sigma q)^2}\right],$$

$$\frac{d^2a_1}{d\sigma^2}=\frac{16}{15}\left\{\frac{1}{q'-\sigma q}-\frac{pq'-qp'}{3\left(1-\frac{2}{3}\frac{p\sigma-p}{q'-q\sigma}\right)}\right\}\left(1-\frac{2}{3}\frac{p\sigma-p'}{q'-q\sigma}\right)^{-\frac{4}{5}}\frac{pq'-p'q}{(q'-\sigma q)^2};$$

putting $p=5[(e)-e]$, $p'=3[(e)-e]$, $q'=6e$, $q=5(2e-m)$.

But $1-\frac{2}{3}\frac{p\sigma-p'}{q-q\sigma}$ is always less than 1, and $q'-\sigma q$, $pq'-p'q$ are both positive and small quantities. Hence $\frac{d^2a_1}{d\sigma^2}$ is positive, and therefore the value of σ, deduced by making $\frac{da_1}{d\sigma}=0$, gives a minimum for a_1. This value is evidently $\sigma=\frac{3q'+2p'}{3q+2p}$.

On substituting this in the value of a_1, we shall have $a_1=0$: $\frac{da_1}{d\sigma}=0$ would be also satisfied by making $\sigma=\infty$, but the supposition that ν is finite and little different from 1, excludes this value. Hence a_1 must increase from its least value as σ decreases to its least value, but this is when $\sigma=1$, or when the shell is supposed to be homogeneous; consequently the greatest value of a_1 will be determined from the equation

$$a_1^5=\frac{\lambda+\frac{5}{4}m-2e}{3\left(\frac{5}{4}m-e\right)}=\frac{2}{3}+\frac{\lambda-\frac{5}{4}m}{3\left(\frac{5}{4}m-e\right)}=\frac{2}{3}+\frac{1}{3}\,\frac{\frac{5}{4}m-(e)}{\frac{5}{4}\,m-e}.$$

From Section IX. $(e)=\frac{1}{294}$ nearly; and using for e and m the values respectively $\frac{1}{300}$ and $\frac{1}{289}$, we shall obtain

$$a_1^5=\frac{1}{3}\left[2+\frac{157\times 50}{172\times 49}\right]=\cdot 97714;$$

hence $a_1=\cdot 99539$, $1-a_1=\cdot 00461$, and therefore, consistently with observation, the least thickness of the earth's crust cannot be less than 18 miles.

From Section III. it appears that as (k) diminishes the more will the constitution of the nucleus and shell be different, and consequently the least value which can be attributed to (k) from observation, may be assumed to give the least value of a_1 in equation (35.). By using this equation together with (29.), I find, after a few trials, that with $a_1=\cdot 85$, the approximate value of Q would be ·023441. But Q increases with a_1, hence the greatest thickness of the shell cannot, on the above assumption, be greater than ·15, or 600 miles nearly.

(3.) *The Earth's Ellipticity when entirely fluid.*

25. By the aid of equation (11.), Part I., the following values of the earth's primitive ellipticity have been obtained with different values of (k).

With $(k)=\cdot 7481$, $E=\frac{1}{302\cdot 22}$,

$(k)=\cdot 896$, $E=\frac{1}{310\cdot 74}$,

$(k)=1\cdot$, $E=\frac{1}{316}$.

The value of the earth's moment of inertia used in these calculations, was deduced by using the value of p found in Section IX., and that of λ found from the lunar inequalities. If the value of the latter quantity, found in the section referred to, were used, the resulting values of E would all be a little smaller; it may therefore be concluded, that *the earth's primitive ellipticity was less than its present ellipticity, although the difference between them may be neglected.*

(4.) *The Direction of great Lines of Elevation on the Surface of the Earth.*

26. If a zone of least disturbance existed near the parallel of mean pressure, the directions of great lines of elevation should be nearly parallel or perpendicular to the equator. Its non-existence there, which observation seems to show, proves at least that the variable pressure did not predominate over the constant pressure.

As yet, observation seems to prove that such a zone does not exist on the earth's surface; and hence from Section VIII. we must provisionally conclude that the constant pressure greatly predominated over the variable pressure, and consequently that the directions of lines of elevation must be comparatively arbitrary. Geological and geographical observations present results which are generally in accordance with these views.

(5.) *The Existence of great Friction and Pressure at the Surface of Contact of the Nucleus and Shell.*

27. The conclusions arrived at in Section IV., combined with the important result obtained by Mr. Hopkins in his second memoir on Physical Geology*, show that great friction and pressure must exist between the shell and fluid nucleus. The result alluded to, as quoted in Mr. Hopkins's third memoir, is

$$\text{“}\,P' - P_1 = \left(1 - \frac{\varepsilon}{\varepsilon_1}\right)\left(1 - \frac{\eta}{1 + \frac{h}{q^5 - 1}}\right) P_1,$$

where P denotes the precession of a solid homogeneous spheroid of which the ellipticity$=\varepsilon_1$, that of the earth's exterior surface, and P' the precession of the earth, supposed to consist of a heterogeneous fluid nucleus contained in a heterogeneous spheroidal shell, of which the interior and exterior ellipticities are respectively ε and ε_1, the transition being immediate from the entire solidity of the shell to the perfect fluidity of the mass." This result was found on the hypothesis of the non-existence of friction and pressure from molecular causes at the surface of contact of the shell and nucleus; if this hypothesis were true, we should have in general, from articles 12 and 13, $P' \angle P_1$, or at least, we could not have $P' 7 P_1$. This result is so different from that obtained by this observation, that we are entitled to assume that the motion of rotation of both shell and nucleus takes place nearly as if the mass were entirely solid. It must evidently result, that at the surface of contact of the solid and fluid, a considerable amount of friction and pressure should necessarily exist. From physical reasons, there is also a great probability of the truth of this proposition. The highly crystalline structure which must necessarily be assigned to the shell's inner surface, combined with the viscidity of the strata of the nucleus in immediate contact with it, would evidently, if sufficiently great, tend constantly to equalize the motions of both shell and nucleus, and to cause the whole to rotate as one mass. Of the truth of the fundamental assumption in article 1, I may therefore venture to hope no reasonable doubt can exist.

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* Philosophical Transactions, 1840, p. 207.

(6.) *The Amount of Elastic Gases given off at the Surface of the Nucleus during different Geological Epochs.*

28. If, in the strata of the nucleus, elastic gases were confined by the compression of the superior strata, it must follow from Section III. that during the solidification of the upper parts of the fluid the rest will tend to expand, and consequently to set free the confined gases. If the amount of elastic gases in a cubic unit of any stratum be proportional to the pressure to which that stratum is subjected, it must follow that the quantity evolved on the solidification of the surface stratum must be proportional to the amount of contraction of that stratum in solidifying. The expansion of the other strata, yet in a fluid state, would also tend to produce an evolution of such gases. The evolution of gases from the solidifying stratum would evidently be proportional to $(1-k)a_1^2$, and from any other stratum with the radius a_1, proportional to the density ϱ of that stratum. But it has been shown in Section III. that in general ϱ and $(1-k)$ decrease as a_1 decreases; hence we may conclude that the amount of elastic gases given off from the surface of the nucleus rapidly decreases as the thickness of the shell increases.

(7.) *The Distribution of the Waters on the Surface of the Globe.*

29. The expressions for the variation of gravity obtained in Section II., show that if the angular velocity of rotation of the earth remained unchanged, the waters on its surface would tend to accumulate towards the equator, by the gradual thickening of the shell and the consequent change in the direction of gravity.

XXIII. *On the Rolling Motion of a Cylinder.* *By the Rev.* HENRY MOSELEY, *M.A., F.R.S., Corresponding Member of the Institute of France.*

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THE oscillatory motion of a heterogeneous cylinder rolling on a horizontal plane has been investigated by EULER*. He has determined the pressure of the cylinder on the plane at any period of the oscillation, and the time of completing an oscillation when the arcs of oscillation are *small.*

The forms under which the cylinder enters into the composition of machinery are so various and its uses so important, that I have thought it desirable to extend this inquiry, and in the following paper I have sought to include in the discussion the case of the *continuous* rolling of the cylinder, and to determine—

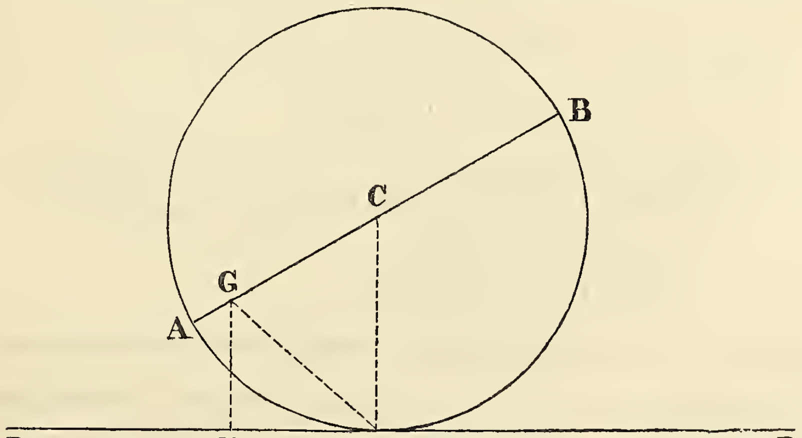
1st. The time occupied by a heterogeneous cylinder in rolling continuously through any given space.

2ndly. The time occupied in its oscillation through any given arc.

3rdly. Its pressure, when thus rolling continuously, on the horizontal plane on which it rolls.

Under the second and third heads this discussion has a practical application to the theory of the pendulum; determining the time occupied in the oscillations of a pendulum through any given arc, whether it rests on a cylindrical axis or on knife-edges, and the circumstances under which it will jump or slip on its bearings; and under the first and third, to the stability and the lateral oscillations of locomotive engines in rapid motion, whose driving-wheels are, by reason of their cranked axles, untruly balanced.

Let AMB represent the section of a heterogeneous cylinder through its centre of



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* Nova Acta Acad. Petropol. 1788. " De motu oscillatorio circa axem cylindricum plano horizontali incumbentem."

gravity G and perpendicular to its axis C; and let M be its point of contact, at any time, with the horizontal plane BD on which it is rolling. Assume

a =AC, h=CG, θ=ACM.

W=weight of cylinder. Wk^2=momentum of inertia of the cylinder about an axis passing through G and parallel to the axis of the cylinder.

ω=given value of the angular velocity $\left(\frac{d\theta}{dt}\right)$ when θ has the given value θ_1.

θ_1=given value of θ when the angular velocity has the given value ω.

l=given value of GM corresponding to the value θ_1 of θ.

Then $\mathrm{W}(k^2+\overline{\mathrm{GM}}^2)=\mathrm{W}(k^2+a^2+h^2-2ah\cos\theta)$=moment of inertia about M. Since moreover the cylinder may be considered to be in the act of revolving about the point M by which it is in contact with the plane, one-half of its *vis viva* is represented by the formula .

$$\frac{1}{2}\,\frac{\mathrm{W}}{g}(k^2+a^2-2ah\cos\theta+h^2)\left(\frac{d\theta}{dt}\right)^2,$$

and one-half of the *vis viva* acquired by it in rolling through the angle $\theta_1-\theta$, by

$$\frac{1}{2}\,\frac{\mathrm{W}}{g}\left\{(k^2+a^2-2ah\cos\theta+h^2)\left(\frac{d\theta}{dt}\right)^2-(k^2+l^2)\omega^2\right\}.$$

But the vertical descent of the centre of gravity while the cylinder is passing from the one position into the other, is represented by

$$h(\cos\theta-\cos\theta_1).$$

Therefore, by the principle of *vis viva**,

$$\frac{1}{2}\,\frac{\mathrm{W}}{g}\left\{(k^2+a^2-2ah\cos\theta+h^2)\left(\frac{d\theta}{dt}\right)^2-(k^2+l^2)\omega^2\right\}=\mathrm{W}h(\cos\theta-\cos\theta_1),$$

whence we obtain

$$\left(\frac{d\theta}{dt}\right)^2=\frac{2gh(\cos\theta-\cos\theta_1)+(k^2+l^2)\omega^2}{k^2+a^2-2ah\cos\theta+h^2}$$

$$=\left(\frac{g}{a}\right)\frac{\cos\theta-\left(\cos\theta_1-\frac{k^2+l^2}{2gh}\omega^2\right)}{\frac{1}{2}\left(\frac{k^2}{ah}+\frac{a}{h}+\frac{h}{a}\right)-\cos\theta}\quad\ldots\ldots\ldots\ldots\quad(1.)$$

Let

$$\alpha=\frac{1}{2}\left(\frac{k^2}{ah}+\frac{a}{h}+\frac{h}{a}\right)\quad\ldots\ldots\ldots\ldots\quad(2.)$$

$$\beta=\cos\theta_1-\left(\frac{k^2+l^2}{2gh}\right)\omega^2\quad\ldots\ldots\ldots\ldots\quad(3.)$$

$$\therefore\quad-\frac{d\theta}{dt}=\left(\frac{g}{a}\right)^{\frac{1}{2}}\left(\frac{\cos\theta-\beta}{\alpha-\cos\theta}\right)^{\frac{1}{2}}\text{ and }t=-\left(\frac{a}{g}\right)^{\frac{1}{2}}\int_{\theta_1}^{0}\left(\frac{\alpha-\cos\theta}{\cos\theta-\beta}\right)^{\frac{1}{2}}d\theta,$$

$$\therefore\quad t=\left(\frac{a}{g}\right)^{\frac{1}{2}}\int_{0}^{\theta_1}\left(\frac{\alpha-\cos\theta}{\cos\theta-\beta}\right)^{\frac{1}{2}}d\theta,\quad\ldots\ldots\ldots\ldots\quad(4.)$$

where t represents the time of the body's passing from the inclination θ_1 to zero.

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* Poisson, Dynamique, 2me partie, 565 ; Poncelet, Mécanique Industrielle ; Moseley, Mechanical Principles of Engineering, Art. 129.

Now let it be observed that in this function $\alpha>\beta$ so long as a is less than g, since

$$k^2+l^2>-(k^2+l^2)\omega^2,\ \text{or}\ k^2+a^2-2ah\cos\theta_1+h^2>-(k^2+l^2)\omega^2,$$

and $$\therefore\ k^2+a^2+h^2>2ah\cos\theta_1-(k^2+l^2)\omega^2,$$

and $$\frac{1}{2}\left(\frac{k^2}{ah}+\frac{a}{h}+\frac{h}{a}\right)>\cos\theta_1-\frac{k^2+l^2}{2ah}\,.\,\omega^2.$$

et $$\frac{1+\alpha}{1+\beta}=p^2,\quad -\frac{1-\alpha}{1-\beta}=q^2,\quad \frac{\alpha-\cos\theta}{\cos\theta-\beta}=q^2\sec^2\phi.$$

Then when $\theta=0$, $$q^2\sec^2\phi=\frac{\alpha-1}{1-\beta}=q^2,\quad\therefore\ \sec\phi=1\ \text{and}\ \phi=0.$$

When $\theta=\theta_1$ let $\phi=\phi_1$,

$$\therefore\ q^2\sec^2\phi_1=\frac{\alpha-\cos\theta_1}{\cos\theta_1-\beta}=\frac{\frac{1}{2}\left(\frac{k^2}{ah}+\frac{h}{a}+\frac{a}{h}\right)-\cos\theta_1}{\left(\frac{k^2+l^2}{2gh}\right)\omega^2}=\left(\frac{g}{a}\right)\frac{k^2+a^2+h^2-2ah\cos\theta_1}{(k^2+l^2)\omega^2}=\frac{g}{a\omega^2};$$

also

$$q^2=-\frac{1-\alpha}{1-\beta}=-\frac{1-\frac{1}{2}\left(\frac{k^2}{ah}+\frac{a}{h}+\frac{h}{a}\right)}{(1-\cos\theta_1)+\left(\frac{k^2+l^2}{2gh}\right)\omega^2}=\left(\frac{g}{a}\right)\frac{k^2+(a-h)^2}{2gh\,\text{vers}\,\theta_1+(k^2+l^2)\omega^2},$$

$$\therefore\ \sec^2\phi_1=\frac{(k^2+l^2)\omega^2+2gh\,\text{vers}\,\theta_1}{\{k^2+(a-h)^2\}\omega^2},\qquad\qquad(5.)$$

Now $$\int_0^{\theta_1}\left(\frac{\alpha-\cos\theta}{\cos\theta-\beta}\right)^{\frac{1}{2}}d\theta=\int_0^{\phi_1}\left(\frac{\alpha-\cos\theta}{\cos\theta-\beta}\right)^{\frac{1}{2}}\frac{d\theta}{d\phi}\,d\phi.$$

And since $$\frac{\alpha-\cos\theta}{\cos\theta-\beta}=q^2\sec^2\phi,$$

$$\therefore\ \frac{2\cos\theta-(\alpha+\beta)}{(\alpha-\beta)}=\frac{\cos^2\phi-q^2}{\cos^2\phi+q^2},$$

$$\therefore\ 2\cos\theta=\frac{(\alpha+\beta)(\cos^2\phi+q^2)+(\alpha-\beta)(\cos^2\phi-q^2)}{\cos^2\phi+q^2}$$

$$\cos\theta=\frac{\alpha\cos^2\phi+\beta q^2}{\cos^2\phi+q^2}\qquad\qquad(6.)$$

$$\sin^2\theta=\frac{(\cos^2\phi+q^2)^2-(\alpha\cos^2\phi+\beta q^2)^2}{(\cos^2\phi+q^2)^2}$$

$$=\frac{(\cos^2\phi+q^2-\alpha\cos^2\phi-\beta q^2)(\cos^2\phi+q^2+\alpha\cos^2\phi+\beta q^2)}{(\cos^2\phi+q^2)^2}$$

$$=\frac{\{(1-\beta)q^2+(1-\alpha)\cos^2\phi\}\{(1+\beta)q^2+(1+\alpha)\cos^2\phi\}}{(q^2+\cos^2\phi)^2}$$

$$=(1-\beta^2)q^2\,.\sin^2\phi\,.\frac{q^2+p^2\cos^2\phi}{(q^2+\cos^2\phi)^2};$$

$$\therefore\ \sin\theta=q(1-\beta^2)^{\frac{1}{2}}\sin\phi\,.\frac{(q^2+p^2\cos^2\phi)^{\frac{1}{2}}}{q^2+\cos^2\phi}.\qquad\qquad(7.)$$

Now

$$\frac{d\theta}{d\phi}=\frac{d\theta}{d\cos\theta}\cdot\frac{d\cos\theta}{d\cos\phi}\cdot\frac{d\cos\phi}{d\phi}=\frac{\sin\phi}{\sin\theta}\cdot\frac{d\cos\theta}{d\cos\phi}. \quad \ldots\ldots\ldots \quad (8.)$$

Also by equation (6.),

$$\frac{d\cos\theta}{d\cos\phi}=\frac{2\alpha(q^2+\cos^2\phi)\cos\phi-2(\alpha\cos^2\phi+\beta q^2)\cos\phi}{(q^2+\cos^2\phi)^2}=\frac{2(\alpha-\beta)q^2\cos\phi}{(q^2+\cos^2\phi)^2};$$

∴ by equations (7.) and (8.),

$$\frac{d\theta}{d\phi}=\frac{2(\alpha-\beta)q^2}{(1-\beta^2)^{\frac{1}{2}}q}\cdot\frac{q^2+\cos^2\phi}{(q^2+p^2\cos^2\phi)^{\frac{1}{2}}}\cdot\frac{\cos\phi}{(q^2+\cos^2\phi)^2}=\frac{2(\alpha-\beta)q}{(1-\beta^2)^{\frac{1}{2}}}\,\frac{\cos\phi}{(q^2+\cos^2\phi)(q^2+p^2\cos^2\phi)^{\frac{1}{2}}},$$

$$\therefore\ \left(\frac{\alpha-\cos\theta}{\cos\theta-\beta}\right)^{\frac{1}{2}}\frac{d\theta}{d\phi}=\frac{2(\alpha-\beta)q^2}{(1-\beta^2)^{\frac{1}{2}}}\cdot\left\{\frac{1}{(q^2+\cos^2\phi)(q^2+p^2\cos^2\phi)^{\frac{1}{2}}}\right\}$$

$$=\frac{2(\alpha-\beta)q^2}{(1-\beta^2)^{\frac{1}{2}}}\cdot\left\{\frac{1}{(q^2+1-\sin^2\phi)(q^2+p^2-p^2\sin^2\phi)^{\frac{1}{2}}}\right\}$$

$$=\frac{2(\alpha-\beta)q^2}{(1-\beta^2)^{\frac{1}{2}}(p^2+q^2)^{\frac{1}{2}}(1+q^2)}\left\{\frac{1}{\left(1-\frac{1}{1+q^2}\sin^2\phi\right)\left(1-\frac{p^2}{p^2+q^2}\sin^2\phi\right)^{\frac{1}{2}}}\right\}$$

$$=\frac{2(\alpha-\beta)q^2}{(1-\beta^2)^{\frac{1}{2}}(p^2+q^2)^{\frac{1}{2}}(1+q^2)}\left\{\frac{1}{(1-n\sin^2\phi)(1-c^2\sin^2\phi)^{\frac{1}{2}}}\right\}.$$

If

$$n=\frac{1}{1+q^2}=\frac{1}{1-\frac{1-\alpha}{1-\beta}}=\frac{1-\beta}{\alpha-\beta}, \quad \ldots\ldots\ldots \quad (9.)$$

and

$$c^2=\frac{p^2}{p^2+q^2}=\frac{\frac{1+\alpha}{1+\beta}}{\frac{1+\alpha}{1+\beta}-\frac{1-\alpha}{1-\beta}}=\frac{(1+\alpha)(1-\beta)}{2(\alpha-\beta)}, \quad \ldots\ldots\ldots \quad (10.)$$

$$\therefore\ \int_0^{\phi_1}\left(\frac{\alpha-\cos\theta}{\cos\theta-\beta}\right)^{\frac{1}{2}*}\frac{d\theta}{d\phi}d\phi=\frac{2(\alpha-\beta)q^2}{(1-\beta^2)^{\frac{1}{2}}(p^2+q^2)^{\frac{1}{2}}(1+q^2)}\int_0^{\phi_1}\frac{d\phi}{(1-n\sin^2\phi)(1-c^2\sin^2\phi)^{\frac{1}{2}}}$$

$$=\frac{2(\alpha-\beta)q^2}{(1-\beta^2)^{\frac{1}{2}}(p^2+q^2)^{\frac{1}{2}}(1+q^2)}\Pi\left(-nc\phi_1\right), \quad \ldots\ldots \quad (11.)$$

where $\Pi(-nc\phi_1)$ is that elliptic function of the third order whose parameter is $-n$ and modulus c.

Now
$$\frac{1}{(p^2+q^2)^{\frac{1}{2}}}=\frac{1}{\left\{\left(\frac{1+\alpha}{1+\beta}\right)-\left(\frac{1-\alpha}{1-\beta}\right)\right\}^{\frac{1}{2}}}=\sqrt{\frac{1-\beta^2}{2(\alpha-\beta)}}$$

$$\frac{q^2}{1+q^2}=\frac{-\left(\frac{1-\alpha}{1-\beta}\right)}{1-\left(\frac{1-\alpha}{1-\beta}\right)}=\left(\frac{\alpha-1}{\alpha-\beta}\right),$$

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* I cannot find that this function has before been integrated, except in the case in which θ is exceedingly small.

$$\therefore \frac{2(\alpha-\beta)q^2}{(1-\beta^2)^{\frac{1}{2}}(p^2+q^2)^{\frac{1}{2}}(1+q^2)}=\frac{2(\alpha-1)}{\sqrt{2(\alpha-\beta)}}=\frac{\left(\frac{k^2}{ah}+\frac{a}{h}+\frac{h}{a}\right)-2}{\sqrt{\left(\frac{k^2}{ah}+\frac{a}{h}+\frac{h}{a}\right)-2\cos\theta_1+\frac{(k^2+l^2)\omega^2}{gh}}}$$

$$=\frac{k^2+(a-h)^2}{\sqrt{ah(k^2+l^2)\left(1+\frac{a\omega^2}{g}\right)}}, \quad \ldots\ldots\ldots\ldots \quad (12.)$$

∴ by equations 11 and 4,

$$t=\frac{k^2+(a-h)^2}{\sqrt{gh(k^2+l^2)\left(1+\frac{a\omega^2}{g}\right)}}.\Pi(-nc\phi_1), \quad \ldots\ldots\ldots\ldots \quad (13.)$$

where (9.) (2.) (3.)

$$n=\frac{1-\beta}{\alpha-\beta}=\frac{1-\cos\theta_1+\frac{k^2+l^2}{2gh}\omega^2}{\frac{1}{2}\left(\frac{k^2}{ah}+\frac{a}{h}+\frac{h}{a}\right)-\cos\theta_1+\frac{k^2+l^2}{2gh}\omega^2}=a\frac{2h \text{ vers } \theta_1+\frac{k^2+l^2}{g}\omega^2}{(k^2+l^2)\left(1+\frac{a\omega^2}{g}\right)}, \quad \ldots\ldots \quad (14.)$$

and (10.) (2.) (3.)

$$c^2=\frac{(1+\alpha)(1-\beta)}{2(\alpha-\beta)}=\frac{\left\{\frac{1}{2}\left(\frac{k^2}{ah}+\frac{h}{a}+\frac{a}{h}\right)+1\right\}\left\{\text{vers }\theta_1+\frac{k^2+l^2}{2gh}\omega^2\right\}ah}{(k^2+l^2)\left(1+\frac{a\omega^2}{g}\right)}$$

$$=\frac{\left\{k^2+(a+h)^2\right\}\left\{\text{vers }\theta_1+\frac{k^2+l^2}{2gh}\omega^2\right\}}{2(k^2+l^2)\left(1+\frac{a\omega^2}{g}\right)}. \quad \ldots\ldots\ldots\ldots \quad (15.)$$

The value of $\Pi(-nc\phi_1)$ being determinable by known methods (Legendre, Fonctions Elliptiques, vol. i. chap. xxiii.), the time of rolling is given by equation 13.

In the case in which the rolling motion is not continuous but oscillatory, we have $\omega=0$; and therefore (equation 5.) $\phi_1=\frac{\pi}{2}$; $\Pi(-nc\phi_1)$ becomes therefore in this case a complete function.

To express the value of this complete elliptic function of the third order in terms of functions of the first and second orders, let

$$\sin^2\psi=\frac{n}{c^2}=\frac{2}{1+\alpha}=\frac{2ah}{k^2+(a+h)^2}. \quad \ldots\ldots\ldots\ldots \quad (16.)$$

Then*

$$\Pi\left(-nc\frac{\pi}{2}\right)=\mathrm{F}\left(c\frac{\pi}{2}\right)+\frac{\tan\psi}{(1-c^2\sin^2\psi)^{\frac{1}{2}}}\left\{\mathrm{F}\left(c\frac{\pi}{2}\right).\mathrm{E}(c\psi)-\mathrm{E}\left(c\frac{\pi}{2}\right).\mathrm{F}(c\psi)\right\},$$

Representing therefore the time of a semi-oscillation by t_1,

$$t_1=\frac{k^2+(a-h)^2}{\sqrt{gh(k^2+l^2)}}\left\{\mathrm{F}\left(c\frac{\pi}{2}\right)+\frac{\tan\psi}{1-c^2\sin^2\psi}\left\{\mathrm{F}\left(c\frac{\pi}{2}\right)\mathrm{E}(c\psi)-\mathrm{E}\left(c\frac{\pi}{2}\right)\mathrm{F}(c\psi)\right\}\right\}, \quad \ldots \quad (17.)$$

where (15.) $$c^2=\frac{k^2+(a+h)^2}{2(k^2+l^2)}\text{ vers }\theta_1. \quad \ldots\ldots\ldots\ldots \quad (18.)$$

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* Legendre, Calcul des Fonctions Elliptiques, vol. i. chap. xxiii. Art. 116.

Since the values of elliptic functions of the first and second orders, having given amplitudes and moduli, are given by the tables of Legendre, it follows that the value of t is given by this formula for all possible values of c and ψ.

If the angle of oscillation θ_1 be very small c is very small, so that its square may be neglected in comparison with unity. In this case

$$\mathrm{F}c\psi=\mathrm{E}c\psi=\psi \text{ and } \mathrm{F}c\tfrac{\pi}{2}=\mathrm{E}c\tfrac{\pi}{2}=\tfrac{\pi}{2},$$

$$\therefore\ \mathrm{F}c\tfrac{\pi}{2}\mathrm{E}c\psi-\mathrm{E}c\tfrac{\pi}{2}\mathrm{F}c\psi=0.$$

For small oscillations therefore

$$t=\frac{k^2+(a-h)^2}{\sqrt{gh(k^2+l^2)}}\cdot\frac{\pi}{2}.\ \ldots\ldots\ldots\ldots \qquad (19.)$$

If the pendulum oscillate on knife-edges $a=0$, $l=h$, and we obtain the well-known theorem of Legendre (Fonctions Elliptiques, vol. i. chap. viii.)

$$t=\sqrt{\frac{k^2+h^2}{gh}}\cdot\mathrm{F}\left(c\frac{\pi}{2}\right),\ \ldots\ldots\ldots\ldots \qquad (20.)$$

where (18.) $c^2=\frac{1}{2}\operatorname{vers}\theta_1=\sin^2\frac{\theta_1}{2}$,

$$\therefore\ c=\sin\frac{1}{2}\theta_1.\ \ldots\ldots\ldots\ldots \qquad (21.)$$

In the case of the small oscillations of a pendulum resting on knife-edge, equation 20. becomes

$$t=\sqrt{\frac{(k^2+h^2)}{gh}}\cdot\frac{\pi}{2},\ \ldots\ldots\ldots\ldots \qquad (22.)$$

which is the well-known formula applicable to that case.

If the pendulum be one which for small arcs beats seconds (21.),

$$1=\sqrt{\frac{k^2+h^2}{gh}}\cdot\pi,$$

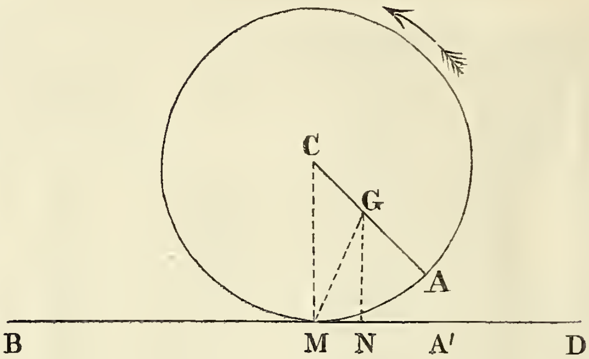
$$\therefore\ (20.)\ 2t=\frac{2\mathrm{F}\left(c\frac{\pi}{2}\right)}{\pi},\ \ldots\ldots\ldots\ldots \qquad (23.)$$

by which equation the time of the oscillation *through any arc*, of a pendulum which oscillates through a *small* arc in one second, may be determined. I have caused the following Table to be calculated from it.

Table of the Time occupied in oscillating through every two degrees of a complete circle, by a Pendulum which oscillates through a small arc in one second.

Arc of oscillation on each side of the vertical in degrees.	Logarithm of $F\left(c\frac{\pi}{2}\right)$ from the tables of LEGENDRE.	Logarithm of $\frac{2}{\pi}.F\left(c\frac{\pi}{2}\right)$.	Time of one complete oscillation in seconds.	Arc of oscillation on each side of the vertical in degrees.	Logarithm of $F\left(c\frac{\pi}{2}\right)$ from the tables of LEGENDRE.	Logarithm of $\frac{2}{\pi}.F\left(c\frac{\pi}{2}\right)$.	Time of one complete oscillation in seconds.
2	0·1961529	0·0000330	1·0001	92	0·2716435	0·0755336	1·1899
4	0·1962521	0·0001322	1·0003	94	0·2752672	0·0791473	1·2000
6	0·1964176	0·0002977	1·0006	96	0·2790010	0·0828811	1·2123
8	0·1966493	0·0005294	1·0012	98	0·2828480	0·0867281	1·2210
10	0·1969473	0·0008274	1·0019	100	0·2868113	0·090614	1·2322
12	0·1973118	0·0011919	1·0027	102	0·2908945	0·0947746	1·2439
14	0·1977430	0·0016231	1·0037	104	0·2951011	0·0989812	1·2560
16	0·1982408	0·0021209	1·0049	106	0·2994353	0·1033154	1·2686
18	0·1988057	0·0026858	1·0052	108	0·3039012	0·1077813	1·2817
20	0·1994377	0·0033178	1·0077	110	0·3085036	0·1123837	1·2953
22	0·2001372	0·0040173	1·0100	112	0·3132474	0·1171275	1·3099
24	0·2009044	0·0047845	1·0110	114	0·3181380	0·1220181	1·3249
26	0·2017396	0·0056197	1·0130	116	0·3231814	0·1270615	1·3400
28	0·2026431	0·0065232	1·0151	118	0·3283839	0·1322640	1·3560
30	0·2036153	0·0074954	1·0174	120	0·3337526	0·1376327	1·3729
32	0·2045494	0·0084295	1·0196	122	0·3392950	0·1431751	1·3905
34	0·2057675	0·0096476	1·0224	124	0·3450196	0·1488997	1·4089
36	0·2069483	0·0108284	1·0252	126	0·3509356	0·1548157	1·4283
38	0·2081996	0·0120797	1·0290	128	0·3570532	0·1609333	1·4486
40	0·2095219	0·0134020	1·0314	130	0·3633838	0·1672639	1·4698
42	0·2109158	0·0147959	1·0347	132	0·3699399	0·1738200	1·4922
44	0·2123818	0·0162619	1·0381	134	0·3767357	0·1806158	1·5157
46	0·2139206	0·0178006	1·0418	136	0·3837869	0·1876670	1·5405
48	0·2155329	0·0194130	1·0457	138	0·3911115	0·1949916	1·5667
50	0·2172193	0·0210994	1·0500	140	0·3987297	0·2026098	1·5944
52	0·2189808	0·0228609	1·0540	142	0·4066647	0·2105448	1·6238
54	0·2208180	0·0246981	1·0585	144	0·4149432	0·2188233	1·6551
56	0·2227319	0·0266120	1·0632	146	0·4235961	0·2274762	1·6884
58	0·2247233	0·0286034	1·0681	148	0·4326595	0·2365396	1·7240
60	0·2267932	0·0306733	1·0732	150	0·4421759	0·2460560	1·7622
62	0·2289427	0·0328228	1·0785	152	0·4521963	0·2560764	1·8032
64	0·2311728	0·0350528	1·0840	154	0·4627819	0·2666620	1·8478
66	0·2334846	0·0373647	1·0898	156	0·4740076	0·2778877	1·8963
68	0·2358794	0·0397595	1·0959	158	0·4859666	0·2898467	1·9491
70	0·2383585	0·0422386	1·1021	160	0·4987770	0·3026571	2·0075
72	0·2409232	0·0448033	1·1087	162	0·5125914	0·3164715	2·0724
74	0·2435750	0·0474551	1·1154	164	0·5276128	0·3314929	2·1453
76	0·2463154	0·0501955	1·1225	166	0·5441204	0·3480005	2·2285
78	0·2491459	0·0530260	1·1298	168	0·5625136	0·3663937	2·3248
80	0·2520684	0·0559485	1·1375	170	0·5833962	0·3872763	2·4393
82	0·2550846	0·0589647	1·1454	172	0·6077506	0·4116307	2·5801
84	0·2581965	0·0620766	1·1536	174	0·6373550	0·4412351	2·7621
86	0·2614060	0·0652861	1·1622	176	0·6760772	0·479907	3·0193
88	0·2647155	0·0685956	1·1711	178	0·7351923	0·5390724	3·4600
90	0·2681272	0·0720073	1·1802	180	Infinite.	Infinite.	Infinite.

The pressure of the cylinder on its point of contact with the plane on which it rolls.



Let A′ be the point where the point A of the cylinder was in contact with the plane.

Let $A'N=x$, $NG=y$.

$-X$=horizontal pressure on M in direction A′M.

Y=vertical pressure on M in direction MC.

Since the centre of gravity G moves as it would do if, the whole mass being collected there, all the impressed forces were applied to it, we have, by the principle of d'Alembert,

$$\left.\begin{aligned} \frac{W}{g}\frac{d^2x}{dt^2}&=-X \\ \frac{W}{g}\frac{d^2y}{dt^2}&=Y-W \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots \quad (28.)$$

But since $CA=a$, $CG=h$, $MCA=\theta$,

$$\therefore \quad x=a\theta-h\sin\theta,$$

$$y=a-h\cos\theta;$$

$$\therefore \quad \frac{dx}{dt}=(a-h\cos\theta)\frac{d\theta}{dt},$$

$$\frac{dy}{dt}=h\sin\theta\frac{d\theta}{dt}$$

$$\therefore \quad \left.\begin{aligned} \frac{d^2x}{dt^2}&=h\sin\theta\left(\frac{d\theta}{dt}\right)^2+(a-h\cos\theta)\frac{d^2\theta}{dt^2} \\ \frac{d^2y}{dt^2}&=h\cos\theta\left(\frac{d\theta}{dt}\right)^2+h\sin\theta\frac{d^2\theta}{dt^2} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (29.)$$

Assume $\left(\frac{d\theta}{dt}\right)^2=M$, $\left(\frac{d^2\theta}{dt^2}\right)=-N$,

$\therefore$ by equation (29.),

$$\frac{d^2x}{dt^2}=Mh\sin\theta-N(a-h\cos\theta)$$

$$\frac{d^2y}{dt^2}=Mh\cos\theta-Nh\sin\theta;$$

by equation (28.),

$$\left.\begin{aligned} X&=\frac{Wh}{g}\left\{-M\sin\theta+N\left(\frac{a}{h}-\cos\theta\right)\right\} \\ Y&=W+\frac{Wh}{g}\left\{M\cos\theta-N\sin\theta\right\}. \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (30.)$$

But by equation (1.), substituting $-\theta$ and $-\theta_1$ for θ and θ_1,

$$\mathrm{M}=\left(\frac{d\theta}{dt}\right)^2=\frac{2gh(\cos\theta-\cos\theta_1)+(k^2+l^2)\omega^2}{k^2+a^2-2ah\cos\theta+h^2} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (31.)$$

$$=\left(\frac{g}{a}\right)\frac{2ah(\cos\theta-\cos\theta_1)+(k^2+l^2)\frac{a\omega^2}{g}}{k^2+a^2-2ah\cos\theta+h^2}$$

$$=\left(\frac{g}{a}\right)\frac{k^2+a^2+h^2-2ah\cos\theta_1+(k^2+l^2)\frac{a\omega^2}{g}-(k^2+a^2+h^2-2ah\cos\theta)}{k^2+a^2-2ah\cos\theta+h^2},$$

$$\therefore \quad \mathrm{M}=\left(\frac{g}{a}\right)\left\{\frac{(k^2+l^2)\left(1+\frac{a\omega^2}{g}\right)}{k^2+a^2+h^2-2ah\cos\theta}-1\right\} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (32.)$$

Observing that $a^2+h^2-2ah\cos\theta_1=l^2$.

Differentiating this equation and dividing by $\left(\frac{d\theta}{dt}\right)$,

$$-\mathrm{N}=\left(\frac{d^2\theta}{dt^2}\right)=-\frac{gh(k^2+l^2)\left(1+\frac{a\omega^2}{g}\right)\sin\theta}{(k^2+a^2+h^2-2ah\cos\theta)^2}. \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (33.)$$

Substituting these values of M and N in equation (30.), and reducing,

$$\mathrm{X}=\frac{\mathrm{W}h\sin\theta}{a}\left\{1-\frac{(k^2+l^2)(k^2+h^2-ah\cos\theta)(g+a\omega^2)}{g(k^2+a^2+h^2-2ah\cos\theta)^2}\right\}. \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (34.)$$

$$\mathrm{Y}=\frac{\mathrm{W}h}{a}\left\{\left(\frac{a}{h}-\cos\theta\right)-\frac{(k^2+l^2)(g+a\omega^2)\{ah\cos^2\theta-(k^2+a^2+h^2)\cos\theta+ah\}}{g(k^2+a^2+h^2-2ah\cos\theta)^2}\right\}. \quad . \ . \quad (35.)$$

The rotation of a body about a cylindrical axis of small diameter.

Assuming $a=0$ in equations (31.), (33.), and $\theta_1=0$, we have

$$\mathrm{M}=\frac{2gh(\cos\theta-1)}{k^2+h^2}+\omega^2 \quad \mathrm{N}=\frac{gh\sin\theta}{k^2+h^2}.$$

Therefore, by equation (30.),

$$\mathrm{X}=\frac{\mathrm{W}h}{g}\left\{\frac{gh(2-3\cos\theta)}{k^2+h^2}-\omega^2\right\}\sin\theta \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (40.)$$

$$\mathrm{Y}=\mathrm{W}+\frac{\mathrm{W}h}{g}\left\{\frac{gh(3\cos^2\theta-2\cos\theta-1)}{k^2+h^2}+\omega^2\cos\theta\right\}. \quad . \ . \ . \ . \ . \quad (41.)$$

The last equation may be placed under the form

$$\mathrm{Y}=\mathrm{W}+\frac{3\mathrm{W}h^2}{k^2+h^2}\left[\left\{\cos\theta+\frac{1}{3}\left(\frac{k^2+h^2}{2gh}\omega^2-1\right)\right\}^2-\frac{1}{9}\left(\frac{k^2+h^2}{2gh}\omega^2-1\right)^2-\frac{1}{3}\right].$$

If $\frac{1}{3}\left(\frac{k^2+h^2}{2gh}\omega^2-1\right)$ be numerically less than unity, whether it be positive or negative, there will be some value of θ between 0 and π for which this expression will be equalled, with an opposite sign, by $\cos\theta$, and for which the first term under the bracket in the value of Y will vanish. This corresponds to a minimum value of Y represented by the formula

$$Y=W-\frac{Wh^2}{k^2+h^2}\left\{\frac{1}{3}\left(\frac{k^2+h^2}{2gh}\omega^2-1\right)^2+1\right\}. \quad . \quad . \quad . \quad . \quad . \quad , \quad . \qquad (42.)$$

But if $\frac{1}{3}\left(\frac{k^2+h^2}{2gh}\omega^2-1\right)$ be numerically greater than unity, then the minimum of Y will be attained when $\theta=\pi$, and when

$$Y=W-\frac{Wh}{g}\left\{\omega^2-\frac{4gh}{k^2+h^2}\right\}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (43.)$$

The jump of an axis.

If Y be negative in any position of the body, the axis will obviously jump from its bearings, unless it be retained by some mechanical expedient not taken account of in this calculation. But if Y be negative in any position, it must be negative in that in which its value is a minimum. If a jump take place at all, therefore, it will take place when Y is a minimum; and whether it will take place or not, is determined by finding whether the minimum value of Y is negative. If therefore the expression (42.) or (43.) be negative, the axis will jump in the corresponding case. An axis of infinitely small diameter, such as we have here supposed, becomes a fixed axis; and the pressure upon a fixed axis, supposed to turn in cylindrical bearings *without friction*, is the same whatever may be its diameter; equations (40.) and (41.) determine therefore that pressure, and equation (42.) or (43.) determines the vertical strain upon the collar when the tendency of the axis to jump from its bearings is the greatest.

The jump of a rolling cylinder.

Whether a jump will or will not take place, has been shown to be determined by finding whether the minimum value of Y be negative or not.

Substituting α for $\frac{1}{2}\left(\frac{k^2}{ah}+\frac{h}{a}+\frac{a}{h}\right)$ and reducing, equation (35.) becomes

$$Y=W\left(1-\frac{h}{a}\cos\theta\right)-\frac{W(k^2+l^2)(g+a\omega^2)}{4ga^2}\left\{\frac{\cos^2\theta-2\alpha\cos\theta+1}{(\alpha-\cos\theta)^2}\right\},$$

or

$$Y=W\left(1-\frac{h}{a}\cos\theta\right)-\frac{W(k^2+l^2)(g+a\omega^2)}{4ga^2}\left\{1-\frac{\alpha^2-1}{(\alpha-\cos\theta)^2}\right\}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (44.)$$

$$\therefore \quad \frac{dY}{d\theta}=W\left\{\frac{h}{a}-\frac{(k^2+l^2)(g+a\omega^2)(\alpha^2-1)}{2ga^2(\alpha-\cos\theta)^3}\right\}\sin\theta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (45.)$$

$$\frac{d^2Y}{d\theta^2}=W\left\{\frac{h}{a}-\frac{(k^2+l^2)(g+a\omega^2)(\alpha^2-1)}{2ga^2(\alpha-\cos\theta)^3}\right\}\cos\theta+\frac{3(k^2+l^2)(g+a\omega^2)(\alpha^2-1)}{2ga^2(\alpha-\cos\theta)^4}\sin^2\theta,$$

$\therefore \quad \frac{dY}{dt}=0$, 1st, when $\frac{h}{a}-\frac{(k^2+l^2)(g+a\omega^2)(\alpha^2-1)}{2ga^2(\alpha-\cos\theta)^3}=0$, 2ndly, when $\theta=\pi$, 3rdly, when $\theta=0$.

The first condition evidently yields a positive value of $\frac{d^2\mathrm{Y}}{d\theta^2}$, since it causes the first term of the preceding equation to vanish; and the second term is essentially positive, α being always greater than unity.

If, therefore, the first condition be possible, or if there be any value of θ which satisfies it, that value corresponds to a position of minimum pressure. Solving in respect to cos θ, we obtain

$$\alpha-\sqrt[3]{\frac{(k^2+l^2)(g+a\omega^2)(\alpha^2-1)}{2gah}}=\cos\theta. \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (46.)$$

The first condition will therefore yield a position of minimum pressure, if

$$\alpha-\sqrt[3]{\frac{(k^2+l^2)(g+a\omega^2)(\alpha^2-1)}{2gah}}\begin{array}{l}>-1\\<+1,\end{array} \text{ or if } \sqrt[3]{\frac{(k^2+l^2)(g+a\omega^2)(\alpha^2-1)}{2gah}}\begin{array}{l}<(\alpha+1)\\>(\alpha-1),\end{array}$$

or if

$$\left.\begin{array}{l}\dfrac{(k^2+l^2)(g+a\omega^2)(\alpha^2-1)}{2gah}\begin{array}{l}<(\alpha+1)^3\\>(\alpha-1)^3,\end{array} \text{ or if } \dfrac{(k^2+l^2)(g+a\omega^2)(\alpha-1)}{2gah(\alpha+1)^2}<1\\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\text{and } \dfrac{(k^2+l^2)(g+a\omega^2)(\alpha+1)}{2gah(\alpha-1)^2}>1\end{array}\right\}, \quad . \ . \ . \ . \quad (47.)$$

or if

$$g+a\omega^2<\frac{2gah(\alpha+1)^2}{(k^2+l^2)(\alpha-1)}, \text{ or } \omega^2<\frac{2gh(\alpha+1)^2}{(k^2+l^2)(\alpha-1)}-\frac{g}{a},$$

and

$$g+a\omega^2>\frac{2gah(\alpha-1)^2}{(k^2+l^2)(\alpha+1)}, \text{ or } \omega^2>\frac{2gh(\alpha-1)^2}{(k^2+l^2)(\alpha+1)}-\frac{g}{a};$$

whence, substituting for α and reducing, we obtain finally, the conditions

$$\omega^2<\left(\frac{g}{a}\right)\frac{\{k^2+(a+h)^2\}^2}{(k^2+l^2)\{k^2+(a-h)^2\}}-\left(\frac{g}{a}\right) \text{ and } \omega^2>\left(\frac{g}{a}\right)\frac{\{k^2+(a-h)^2\}^2}{(k^2+l^2)\{k^2+(a+h)^2\}}-\left(\frac{g}{a}\right) \quad . \quad (48.)$$

Of these inequalities the second always obtains, because

$$\{k^2+(a-h)^2\}^2<(k^2+l^2)\{k^2+(a+h)^2\},$$

whatever be the values of k, a and h. And the first is always possible, since

$$\{k^2+(a+h)^2\}^2>(k^2+l^2)\{k^2+(a-h)^2\}.$$

If the *first* obtain, there are two corresponding positions of CA on either of the vertical, determined by equation (46.), in which the pressure Y of the cylinder upon the plane is a minimum.

Substituting the other two values (π and 0) of θ which cause $\frac{d\mathrm{Y}}{dx}$ to vanish, in the value of $\frac{d^2\mathrm{Y}}{d\theta^2}$ we obtain the values

$$-\left\{\frac{h}{a}-\frac{(k^2+l^2)(g+a\omega^2)(\alpha-1)}{2ga^2(\alpha+1)^2}\right\} \text{ and } \left\{\frac{h}{a}-\frac{(k^2+l^2)(g+a\omega^2)(\alpha+1)}{2ga^2(\alpha-1)^2}\right\},$$

or

$$-\frac{h}{a}\left\{1-\frac{(k^2+l^2)(g+a\omega^2)(\alpha-1)}{2gha(\alpha+1)^2}\right\} \text{ and } \frac{h}{a}\left\{1-\frac{(k^2+l^2)(g+a\omega^2)(\alpha+1)}{2gha(\alpha-1)^2}\right\}, \quad . \ . \ . \ . \quad (49.)$$

which expressions are both negative if the inequalities (47.) obtain. The same conditions which yield minimum values of Y in two corresponding oblique positions of CA, yield, therefore, maximum values in the two vertical positions; so that if the inequalities (48.) obtain, there are two positions of maximum and two of minimum pressure.

Substituting the value of cos θ (equation 46) in equation (44.), and reducing, we obtain for the minimum value of Y in the case in which the inequalities (48.) obtain,

$$Y=\frac{W}{4a^2}\Big\{2(a^2-k^2-h^2)-(k^2+l^2)\Big(1+\frac{a\omega^2}{g}\Big)+3\sqrt[3]{(k^2+l^2)\{k^2+(a+h)^2\}\{k^2+(a-h)^2\}\Big(1+\frac{a\omega^2}{g}\Big)}$$

If this expression be negative the cylinder will jump.

In the case in which $\omega=0$, which is that of a *pendulum* having a cylindrical axis of finite diameter, it becomes

$$Y=\frac{W}{4a^2}\Big\{2a^2-2h^2-3k^2-l^2+3\sqrt[3]{(k^2+l^2)\{k^2+(a+h)^2\}\{k^2+(a-h)^2\}}\Big\}^{*}. \quad . \quad . \quad (50.)$$

If the first of the inequalities (48.) do not obtain, no position of minimum pressure corresponds to equation (46.); and the inequalities (47.) do not obtain, so that the values (49.) of $\frac{d^2Y}{d\theta^2}$, given respectively by the substitution of π and 0 for θ, are no longer both negative, but the second only. In this case the value π of θ is that, therefore, which corresponds to a position of minimum pressure, which minimum pressure is determined by substituting π for θ in equation (35.), and is represented by

$$Y=W\Big(1+\frac{h}{a}\Big)-\frac{W(k^2+l^2)(g+a\omega^2)}{4ga^2}\Big\{1-\frac{\alpha^2-1}{(\alpha+1)^2}\Big\}=\frac{W}{a}\Big\{a+h-\frac{(k^2+l^2)(g+a\omega^2)}{2ga(\alpha+1)}\Big\}=\frac{W}{a}\Big\{a+h-\frac{h(k^2+}{g\{k^2}$$

$$Y=\frac{W}{a}\left\{a+h-\frac{h\Big\{k^2+(a+h)^2-4ah\cos^2\frac{1}{2}\theta_1\Big\}(g+a\omega^2)}{g\{k^2+(a+h)^2\}}\right\}=\frac{W}{a}\left\{a+h-\frac{h}{g}\Big\{1-\frac{4ah\cos^2\frac{1}{2}\theta_1}{k^2+(a+h)^2}\Big\}(g+a\omega^2)\right\},$$

$$\therefore\ Y=W\left\{1-\frac{h\omega^2}{g}+\frac{4h^2\Big(1+\frac{a\omega^2}{g}\Big)\cos^2\frac{1}{2}\theta_1}{k^2+(a+h)^2}\right\}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (51.)$$

The cylinder will jump if this expression be negative, that is, if

$$\frac{h\omega^2}{g}>1+\frac{4h^2\Big(1+\frac{a\omega^2}{g}\Big)\cos^2\frac{1}{2}\theta_1}{k^2+(a+h)^2},\ \text{or if}\ \frac{\omega^2h}{g}\left\{1-\frac{4h\cos^2\frac{1}{2}\theta_1}{k^2+(a+h)^2}\right\}>1+\frac{4h^2\cos^2\frac{1}{2}\theta_1}{k^2+(a+h)^2};$$

or, substituting and reducing, if

$$\omega^2>\frac{g}{h}\left\{1+\frac{4h(a+h)\cos^2\frac{1}{2}\theta_1}{k^2+l^2}\right\}.$$

If the angular velocity ω be assumed to be that acquired in the highest position of the centre of gravity, $\theta_1=\pi$, and $\cos\frac{1}{2}\theta_1=0$. In this case, therefore, (equation 51.)

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* When the pendulum oscillates on knife-edges $a=0$, and this expression assumes the form of a vanishing fraction, whose value may be determined by the known rules. See the next article.

$$Y=W\left(1-\frac{h\omega^2}{g}\right); \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (52.)$$

and there will be a jump if $\omega^2>\frac{g}{h}$. (53.)

The Pendulum oscillating on knife-edges.

In this case a is evanescent, and $\omega=0$. Equations (31.) and (33.) become, therefore,

$$M=\frac{2gh\,(\cos\theta-\cos\theta_1)}{k^2+h^2} \text{ and } N=\frac{gh\sin\theta}{k^2+h^2}.$$

Substituting these values of M and N in equation (30.),

$$X=\frac{Wh^2}{k^2+h^2}\left\{-2\,(\cos\theta-\cos\theta_1)\sin\theta-\cos\theta\sin\theta\right\},\ Y=W+\frac{Wh^2}{k^2+h^2}\left\{(\cos\theta-\cos\theta_1)\cos\theta-\sin^2\theta\right\};$$

$$\therefore\quad X=\frac{Wh^2}{k^2+h^2}(2\cos\theta_1-3\cos\theta)\sin\theta \quad . \; . \; . \; . \; . \; . \; . \; . \quad (54.)$$

$$Y=\frac{Wh^2}{k^2+h^2}\left(3\cos^2\theta-2\cos\theta\cos\theta_1+\frac{k^2}{h^2}\right). \quad . \; . \; . \; . \; . \; . \quad (55.)$$

Y is a minimum when $\cos\theta=\frac{1}{3}\cos\theta_1$, in which case

$$Y=\frac{Wh^2}{k^2+h^2}\left(\frac{k^2}{h^2}-\frac{1}{3}\cos\theta_1\right). \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (56.)$$

There will therefore be a jump of the pendulum upon its bearings at each oscillation, if the amplitude θ_1 of the oscillation be such, that

$$\frac{1}{3}\cos\theta_1>\frac{k^2}{h^2}, \text{ or } \cos^2\theta_1>\frac{3k^2}{h^2}.$$

The jump of the falsely-balanced Carriage-wheel.

The theory of the falsely-balanced carriage-wheel differs from that of the rolling cylinder,—1st, in that the inertia of the carriage applied at its axle influences the acceleration produced by the weight of the wheel, as its centre of gravity descends or ascends in rolling; and 2ndly, in that the wheel is retained in contact with the plane by the weight of the carriage. The first cause may be neglected, because the displacement of the centre of gravity is always in the carriage-wheel very small, and because the angular velocity is, compared with it, very great.

If W_1 represent that portion of the weight of the carriage which must be overcome in order that the wheel may jump (which weight is supposed to be borne by the plane), and if Y_1 be taken to represent the pressure upon the plane, then (equation 52.)

$$Y_1=W_1+Y=W_1+W\left(1-\frac{h\omega^2}{g}\right). \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (57.)$$

In order that there may be a jump, this expression must be negative,

or

$$\frac{Wh\omega^2}{g} > W+W_1 \text{ or } \omega^2 > \frac{g}{h}\left(1+\frac{W_1}{W}\right), \quad \ldots \ldots \ldots \quad (58.)$$

or

$$h > \frac{g}{\omega^2}\left(1+\frac{W_1}{W}\right) \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (59.)$$

The Driving-Wheel of a Locomotive Engine.

The attention of engineers was some years since directed to the effects which might result from the false balancing of a wheel by accidents on railways, which appeared to be occasioned by a tendency to jump in the driving-wheels of the engines. The cranked axle in all cases destroys the balance of the driving-wheel unless a counterpoise be applied; at that time there was no counterpoise, and the axle was so cranked as to displace the centre of gravity more than it does now. Mr. George Heaton, of Birmingham, appears to have been principally instrumental in causing the danger of this false balancing of the driving-wheels to be understood. By means of an ingenious apparatus*, which enabled him to roll a falsely-balanced wheel round the circumference of a table with any given velocity, and to make any required displacement of the centre of gravity, he showed the tendency to jump, produced even by a very small displacement, to be so great, as to leave no doubt on the minds of practical men as to the danger of such displacement in the case of locomotive engines, and a counterbalance is now, I believe, always applied. To determine what is the degree of accuracy required in such a counterpoise, I have calculated from the preceding formulæ that displacement of the centre of gravity of a driving-wheel of a locomotive engine, which is necessary to cause it to jump at the high velocities not unfrequently attained at some parts of the journey of an express train; from such information as I have been able to obtain as to the dimensions of such wheels, and their weights, and those of the engines†. The weight of a pair of driving-wheels, six feet in diameter, with a cranked axle, varies, I am told, from $2\frac{1}{2}$ to 3 tons; and that of an engine on the London and Birmingham Railway, when filled with water, from 20 to 25 tons. If n represent the number of miles per hour at which the engine is travelling, it may be shown by a simple calculation, that the angular velocity, in feet, of a six-feet wheel is represented by $\frac{22n}{45}$, or by $\frac{1}{2}n$ very nearly. In this case we have, therefore,—since W represents the weight of a single wheel and its portion of the axle, and W_1 represents the weight, exclusive of the driving-wheels, which must be raised that either side of the engine may jump*, that is, half the weight of the engine exclusive of the driving-wheels,—$W=1\frac{1}{4}$ to $1\frac{1}{2}$ tons, $W_1=8\frac{3}{4}$ to $11\frac{1}{4}$ tons, $\omega=\frac{1}{2}n$, $g=32{\cdot}19084$; whence I have made the following calculations from formula (59.).

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* This apparatus is exhibited by Professor Cowper in his lectures on machinery at King's College. It has also been placed by Col. Morin among the apparatus of the Conservatoir des Arts et Métiers at Paris.

† I have not included in this calculation the inertia of the crank rods, of the slide gearing, or of the piston and piston rods. The effect of these is to increase the tendency to jump produced by the displacement of the centre of gravity of the wheel; and the like effect is due to the thrust upon the piston rod. The discussion of these subjects does not belong to my present paper.

Weight of the engine in tons, including the driving-wheels.	Weight of a pair of wheels with cranked axle, in tons.	Formula (59.) reduced, $h > \frac{128{\cdot}76\left(1+\frac{W_1}{W}\right)}{n^2}$	Displacement of the centre of gravity of a six-feet driving-wheel, which will cause a jump of the wheel on the rail.		
			Rate of travelling in miles per hour.		
			50.	60.	70.
20	2·5	$\frac{1030{\cdot}08}{n^2}$	·4128	·2867	·2106
	3	$\frac{858{\cdot}4}{n^2}$	·3434	·2384	·1751
25	2·5	$\frac{1287{\cdot}6}{n^2}$	·5150	·3576	·2628
	3	$\frac{1073}{n^2}$	·4292	·2908	·2189

It appears, by formula (59.), that the displacement of the centre of gravity necessary to produce a jump at any given speed, is not dependent on the actual weight of the engine or the wheels, but on the ratio of their weights; and, from the above Table, that when the weight of the engine and wheels is $6\frac{2}{3}$ times that of the driving-wheels, a displacement of $2\frac{3}{4}$ inches in the centre of gravity is enough to create a jump when the train is travelling at sixty miles an hour, or of 2 inches when it is travelling at seventy miles; this displacement varying inversely as the square of the velocity is less, other things being the same, as the square of the diameter of the wheel is less; for the radius of the wheel being represented by a, the angular velocity is represented by $\omega=\frac{22n}{15a}$, and substituting this value, formula (59.) becomes

$$h>\left(\frac{15}{22}\right)^2\frac{ga^2\left(1+\frac{W_1}{W}\right)}{n^2}.$$

If the weight W of the wheel be supposed to vary as the square of its diameter and be represented by μa^2, this formula will become

$$h>\left(\frac{15}{22}\right)^2\frac{g\left(a^2+\frac{W_1}{\mu}\right)}{n^2},$$

---

* It will be observed, that the cranks being placed on the axle at right angles to one another, when the centre of gravity on the one side is in a favourable position for jumping, it is in an unfavourable position on the other side, so that it can only jump on one side at once, and the efforts on the two sides alternate.

still showing the displacement of the centre of gravity necessary to produce a jump to diminish with the diameter of the wheel. These conclusions are opposed to the use of light engines and small driving-wheels; and they show the necessity of a careful attention to the true balancing of the wheels of the carriages as well as the driving-wheels of the engine. It does not follow that every jump of the wheel would be high enough to lift the edge of the flange off the rail; the determination of the height of the jump involves an independent investigation. Every jump nevertheless creates an oscillation of the springs, which oscillation will not of necessity be completed when the jump returns; but as the jumps are made alternately on opposite sides of the engine, it is probable that they may, and that after a time they will, so synchronize with the times of the oscillations, as that the amplitude of each oscillation shall be increased by every jump, and a rocking motion be communicated to the engine attended with danger.

Whilst every jump does not necessarily cause the wheel to run off the rail, it nevertheless causes it to *slip* upon it, for before the wheel jumps it is clear that it must have ceased to have any hold upon the rail or any friction.

The Slip of the Wheel.

If f be taken to represent the coefficient of friction between the surface of the wheel and that of the rail, the actual friction in any position of the wheel will be represented by $Y_1 f$. But the friction which it is necessary the rail should supply, in order that the rolling of the wheel may be maintained, is X. It is a condition therefore necessary to the wheel *not slipping* that

$$Y_1 f > X, \text{ or } f > \frac{X}{Y_1}. \quad \ldots\ldots\ldots \quad (60.)$$

If, therefore, taking the maximum value of $\frac{X}{Y_1}$ in any revolution, we find that f exceeds it, it is certain that the wheel cannot have slipped in that revolution; whilst if, on the other hand, f falls short of it, it must have slipped*. The positions between which the slipping will take place continually, are determined by solving, in respect to $\cos\theta_1$, the equation

$$f = \frac{X}{Y_1}. \quad \ldots\ldots\ldots \quad (61.)$$

The application of these principles to the slip of the carriage-wheel is rendered less difficult by the fact, that the value of h is always in that case so small, as compared with the values of k and a, that $\frac{h}{a}$ may be neglected in formulæ (34.) and (35.), as compared with unity. Those equations then become

$$X = \frac{Wh\sin\theta}{a}\left\{1 - \frac{k^2(g + a\omega^2)}{g(k^2 + a^2)}\right\} \quad \ldots\ldots\ldots \quad (62.)$$

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[*] Of course, the slipping, in the case of the driving-wheels of a locomotive, is diminished by the fact that whilst one wheel is not biting upon the rail the other is.

and

$$Y=\frac{Wh}{a}\left\{\frac{a}{h}-\cos\theta+\frac{(g+a\omega^2)\cos\theta}{g}\right\}=W\left\{1+\frac{h\omega^2\cos\theta}{g}\right\},$$

whence we obtain

$$Y_1=W_1+W\left\{1+\frac{h\omega^2\cos\theta}{g}\right\}\quad\ldots\ldots\ldots\ldots\ldots\quad(63.)$$

and

$$\frac{X}{Y_1}=\frac{\frac{Wh}{a}\left\{1-\frac{k^2(g+a\omega^2)}{g(k^2+a^2)}\right\}\sin\theta}{W_1+W\left\{1+\frac{h\omega^2\cos\theta}{g}\right\}}=\frac{\frac{g}{a\omega^2}\left\{1-\frac{k^2(g+a\omega^2)}{g(k^2+a^2)}\right\}\sin\theta}{\left(1+\frac{W_1}{W}\right)\frac{g}{h\omega^2}+\cos\theta}\quad\ldots\ldots\quad(64.)$$

Assume

$$\beta=\left(1+\frac{W_1}{W}\right)\frac{g}{h\omega^2}\text{ and }u=\frac{\sin\theta}{\beta+\cos\theta}$$

$$\therefore\quad\frac{du}{d\theta}=\frac{1+\beta\cos\theta}{(\beta+\cos\theta)^2}\quad\frac{d^2u}{d\theta^2}=\frac{\{-\beta(\beta+\cos\theta)+2(1+\beta\cos\theta)\}\sin\theta}{(\beta+\cos\theta)^3}.$$

Now if $\beta>1$, there will be some value of θ for which $\frac{1}{\beta}+\cos\theta=0$, and therefore $1+\beta\cos\theta=0$; and since for this value of θ, $\frac{du}{d\theta}=0$, and $\frac{d^2u}{d\theta^2}=-\frac{\beta^2}{(\beta^2-1)^{\frac{3}{2}}}$, it follows that it corresponds to a maximum value of u, and therefore of $\frac{X}{Y}$.

But if $\beta<1$, then there is some value of $\cos\theta$ for which $\beta+\cos\theta=0$, and therefore for which $u=$infinity, which value corresponds therefore in this case to the maximum of $\frac{X}{Y}$.

Thus then it appears that according as

$$\beta\text{ or }\left(1+\frac{W_1}{W}\right)\frac{g}{h\omega^2}\lessgtr 1\text{ or }\omega^2\gtrless\frac{g}{h}\left(1+\frac{W_1}{W}\right)\quad\ldots\ldots\quad(65.)$$

the maximum value of $\frac{X}{Y_1}$ is attained when $\cos\theta=-\beta$ or $=-\frac{1}{\beta}$; that is, when

$$\cos\theta=-\frac{g}{h\omega^2}\left(1+\frac{W_1}{W}\right)\text{ or }=-\frac{h\omega^2}{g\left(\frac{W_1}{W}+1\right)}.\quad\ldots\ldots\quad(66.)$$

In the one case the maximum value of $\frac{X}{Y_1}$ will be infinity, ... (67.)

and in the other case it will be represented by the formula

$$\frac{X}{Y_1}=\frac{g\left\{1-\frac{k^2(g+a\omega^2)}{g(k^2+a^2)}\right\}}{\left\{g^2\left(1+\frac{W_1}{W}\right)^2-h^2\omega^4\right\}^{\frac{1}{2}}}.\quad\ldots\ldots\ldots\ldots\quad(68.)$$

In the first case, *i. e.* when $\beta<1$, the wheel will slip every time that it revolves, whatever may be the value of f. In the second case, or when $\beta>1$, it will slip if f do not exceed the number represented by formula (68.). The conditions (65.) are obviously the same with those (59.) which determine whether there be a jump or not, which agrees with an observation in the preceding article, to the effect, that as the wheel must cease to bite upon the rail before it can jump, it must always slip before it can jump. When the conditions of slipping obtain, one of the wheels always biting when the other is slipping, and the slips of the two wheels alternating, it is evident that the engine will be impelled forwards, at certain periods of each revolution, by one wheel only, and at others, by the other wheel only; and that this is true irrespective of the action of the two pistons on the crank, and would be true if the steam were thrown off. Such alternate propulsions on the two sides of the train cannot but communicate alternate oscillations to the buffer-springs, the intervals between which will not be the same as those between the propulsions; but they may so synchronize with a series of propulsions as that the amplitude of each oscillation may be increased by them until the train attains that fish-tail motion with which railway travellers are familiar. It is obvious that the results shown here to follow from a displacement of the centres of gravity of the driving-wheels, cannot fail also to be produced by the alternate action of the connecting rods at the most favourable driving points of the crank and at the dead points*, and that the operation of these two causes may tend to neutralize or may exaggerate one onother. It is not the object of this paper to discuss the question under this point of view.

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* A slip of the wheel may thus be, and probably is, produced at each revolution.

Wandsworth, Feb. 28, 1851.

XXIV. *Observations upon the Anatomy and Physiology of* Salpa *and* Pyrosoma.

By Thomas Henry Huxley, *Assistant-Surgeon R.N.*
(*late of H.M.S. "Rattlesnake"*). *Communicated by Prof.* Edward Forbes, *F.R.S.*

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1. The *Salpæ*, those strange gelatinous animals, through masses of which the voyager in the great ocean sometimes sails day after day, have been the subject of great controversy since the time of the publication of the celebrated work of Chamisso, 'De Animalibus quibusdam è classe Vermium Linnæana.'

In this work were set forth, for the first time, the singular phenomena presented by the reproductive processes of these animals,—phenomena so strange, and so utterly unlike anything then known to occur in the whole province of zoology, that Chamisso's admirably clear and truthful account was received with almost as much distrust as if he had announced the existence of a veritable Peter Schlemihl.

In later days an opposite fate has fallen upon the statements in question. They have been made the keystone of a revived* theory, and the phenomena presented by the *Salpæ* have been cited as "glaring instances" of a law governing the vast majority of the lower invertebrata—the law of the "Alternation of Generations."

2. There appeared then to be two main points to be kept in view in examining the *Salpæ*:—1st. Are the statements made by Chamisso correct? and 2ndly, if they be correct, how far is the "alternation theory" a just and sufficient generalization of the phenomena?

3. These questions, however, could not be entered upon without a thorough preliminary study of the structure of the *Salpæ*, the opportunities for which are granted but to few.

Such opportunities were afforded to the writer of the present paper at Cape York, in November 1849: for a time the sea was absolutely crowded with *Salpæ*, in all states of growth, and of a size very convenient for examination. At subsequent periods the writer had occasion repeatedly to verify the results at which he had arrived, and to find strong analogical confirmation in the structure of *Pyrosoma* and other allied genera†.

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* Not new, see (70.).

† Those who are acquainted with the nature of the service on which H.M.S. 'Rattlesnake' was engaged, will readily comprehend that the author's investigations were almost *necessarily* original, and independent of anything going on in Europe.

It is the more necessary to state this, as it will be seen, in the historical part of this paper, that M. Krohn,

4. It is proposed in the following pages to consider—

I. The structure of the species of *Salpa* examined.

II. The structure of *Pyrosoma.*

III. The homology of structure of *Salpa* and *Pyrosoma,* and of these with the ordinary Ascidians.

IV. The history of our knowledge of the *Salpæ.*

I. *The Structure of* Salpa.

5. Before entering upon this question, there is a point of some importance to be determined, as to the upper and lower surfaces, the anterior and posterior extremities of the *Salpæ.* Observation will not decide this apparently simple matter, for as the writer has frequently seen, they swim indifferently with either end forward and with either side uppermost; and the determinations of authors are most contradictory.

Throughout the present paper, that side on which the heart is placed will be considered as the dorsal side; that on which the ganglion and auditory vesicle are placed, as the ventral side. That extremity to which the mouth is turned will again be considered as the anterior extremity, the opposite as the posterior. Such a view of the case appears to be more harmonious with the determinations of corresponding parts in other animals than any other. In all the invertebrata the mouth end is always considered as the anterior, the heart side as the dorsal side.

6. The two so-called species of *Salpa* examined were the *S. democratica* of Forskahl, *spinosa* of Otto, and the *S. mucronata* of Forskahl, *pyramidalis* of Quoy and Gaimard. They are described by Sars as *S. spinosa* and *S. mucronata,* or rather as *S. spinosa, proles solitaria,* and *S. spinosa, proles gregaria.* This however begs the question, as to the truth of Chamisso's theory, and I shall therefore prefer to name the two forms I observed simply *Salpa* A and *Salpa* B.

At Cape York, and only there, these two forms were always obtained together. They were of about the same size, but so totally distinct in appearance, that, had they belonged to any other genus, they would have been justly regarded as separate species.

7. *Salpa* A (Plate XV. fig. 1).—The body is gelatinous, transparent and colourless, except the nucleus (*i*), which has a deep reddish-brown tint. It has a general square prismatic shape, and is abruptly truncated and somewhat convex at each extremity. The posterior extremity is provided with eight hornlike processes, which project backwards. Two of these are short and hook-like, placed one before the other in the median line at the posterior part of the superior surface. On the upper part of the

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in the Ann. des Sciences for 1846, has completely anticipated the chief results arrived at, a fact of which the author was totally unaware until his arrival in England in the end of 1850.

Still, as M. Krohn gives merely his conclusions without details or figures, his promised memoir not having appeared (so far as the writer of the present paper is aware), it is hoped that this anticipation will, by showing that perfectly independent observers arrive at the same result, rather tend to increase than to diminish any weight that may be attached to the present researches.

lateral surfaces there is, on each side, a short process. From about midway between the upper and lower edges of this surface, a long, conical process curves upwards and backwards; these processes are distinguished from the others by containing a cæcal process of the system of sinuses in their base (*y*).

Close to the lower edge of the lateral surfaces there is another short process like the uppermost one.

The respiratory apertures are wide and provided with valvular lips. The posterior (*b*) is narrower, and has the valvular lip more marked.

The ganglion (*d*) is less than one-fourth of the length of the body distant from the anterior respiratory aperture.

The otolithes are four in number, hemispherical, and with a dark, blackish brown coloured spot on their external surface, Plate XVI. fig. 5.

The endostyle (*c*) is nearly half the length of the body (reaches as far as the sixth muscular band, counting from before backwards).

The outer surface of the integument is everywhere covered with minute asperities, like little prickles.

The muscular bands (*k*) are seven in number, and, with the exception of the anterior and posterior, completely encircle the body of the animal. This form was always free and solitary*.

8. *Salpa* B, Plate XV. fig. 2, on the other hand, is thus characterized. The body is subovoid, smaller at the posterior extremity than at the anterior (*a*); the former ends in a point, the latter in a small square facet.

The sides are flattened into several irregular facets, and the upper and lower edges are sometimes somewhat carinated. The apertures are similar in general structure to those of the form A, and the anterior and posterior extremities project considerably beyond them.

The ganglion (*d*) is placed at about one-fourth of the length of the body from the anterior extremity. The otolithes resembled those of A.

The endostyle (*c*) is not nearly equal in length to half the body; it does not extend so far back as to the third muscular band.

The outer surface of the integument is smooth.

The muscular bands (*k*) are five in number, and none of them encircle the body of the animal, the dorsal extremities being always separated by a considerable interval. This form, when young, was sometimes found in chains; the adults were always separate.

These forms, it will be observed, are widely different, and the difference is as great between the youngest forms of each as between the adults, so that they are not derived from one another by any species of metamorphosis, properly so called.

Whatever be their external differences, however, their internal organization is so similar that the same description applies to both.

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* The statements of Meyen (*op. cit.*) to the contrary are certainly erroneous.

9. The *Salpa*, then, may be considered as a hollow cylinder, consisting of two tunics, an external and an internal (α, β), the former (α) forming the mantle, the latter (β) the wall of the respiratory cavity. These tunics are continuous with one another at the respiratory apertures, but elsewhere they are separated by a more or less wide space.

In very young *Salpæ* this space is like the cavity of a serous sac, but in the older forms it becomes broken up into smaller channels by the adhesion of the inner and outer tunics to one another at various places, and so constitutes a system of sinuses; it may be conveniently called the "sinus system."

10. Running obliquely from behind forwards and downwards, a thickish column or band (e) crosses the respiratory cavity; it is hollow, and its cavity opens above and below into the sinus system. This is the "gill."

It presents an edge anteriorly and superiorly, and on each side of this, the lateral surfaces are beset with a series of small, oval, ciliated spaces. In this species the gill has but a single grand sinus running through it, and presents no appearance of vascular ramifications. The name gill has been applied to this structure somewhat too exclusively, as there can be little doubt that the whole respiratory cavity performs the branchial function. It is proposed, therefore, to call it the *hypopharyngeal* band, on the supposition that the proper respiratory cavity of the Ascidians answers to an enlarged pharynx.

11. The muscular bands (k) are closely adherent to the inner tunic; they are composed of flattened fibrils, about $\frac{1}{1200}$th of an inch in diameter, which are very distinctly transversely striated, the striæ being about $\frac{1}{7000}$th of an inch apart. The bands appear to possess no sarcolemma.

12. The intestinal canal (Plate XV. figs. 5 and 6) commences by a wide somewhat quadrangular mouth (r) opening into a flattened œsophagus, and placed at the re-entering angle formed by the hypopharyngeal band and the upper wall of the respiratory cavity. The intestine passes backwards, then becomes suddenly bent upwards upon itself, and curving slightly to the right, terminates in a wide flattened anus, close above and to the right side of the mouth (s).

A wide cæcal sac (t), given off on the left side of the intestine and bending upwards and to the right side, constitutes the stomach.

13. There is a very peculiar appendage to the intestinal canal, hitherto, it is believed, quite undescribed, and consisting of a system of delicate, transparent, colourless tubes, with clear contents, arising by a single stem from the upper part of the stomachal cæcum, and thence ramifying over the surface of the intestine (5, 6, u), on what may be called the rectum, that is, the terminal portion of the intestine; it forms a sort of expansion of parallel anastomosing vessels, which all terminate at the same distance from the anus anteriorly, and from the bend of the intestine posteriorly, either by uniting with one another or in small pyriform cæca, Plate XV. figs. 5 and 6.

Do these represent a hepatic organ, or are they not more probably a sort of rudimentary lacteal system, a means of straining off the nutritive juices from the stomach into the blood by which these vessels are bathed?

The intestine is connected with the parietes of the sinus in which it lies by innumerable delicate short threads, like a fine areolar tissue.

14. In *Salpa* A, the only other organ contained in the circum-visceral sinus, besides the intestine and "system of tubes," is a mass of clear cells (*æ*), rendered polygonal by mutual pressure, and placed at the upper and back part of the sinus; to this body the name of "elæoblast" has been given by KROHN. It has by some authors been confounded with a liver, an organ to which it certainly has no analogy whatever. The elæoblast is much larger and more conspicuous in the young than in the adult *Salpæ*, and frequently, but not always, its cells contain an oily matter.

There would seem to be no clue either to the homology or to the function of this elæoblast. Without hazarding a conjecture, it may be remarked, as a curious fact, that these animals, so remarkable for possessing in the fœtal state a true though rudimentary placental circulation, possess an organ which in structure and duration somewhat calls to mind the thymus gland.

15. The nervous system consists of a single subspherical ganglion (*d*), situated in the space between the inner and outer tunics, just where the anterior and lower extremity of the hypopharyngeal band joins the ventral paries. It gives off two delicate branches forward to the "languet" (16.), and a great many in all directions to the parietes of the body. There were no branches traceable specially to the mouth or towards the œsophagus.

A delicate but strong vesicle attached to the anterior and lower surface of the ganglion, and containing four subhemispherical calcareous bodies, with black pigment spots on their outer surface, evidently represents the auditory vesicle and its otolithes in the gasteropod and acephalous Mollusca: and a conical depression in the outer tunic leading towards this auditory vesicle, would appear to be intended to bring it into closer relation with the surrounding medium, Plate XVI. fig. 5.

16. There would appear to be yet another organ of special sense, composed of the "languet" (*f*) and the "ciliated fossa" (*w*), called by ESCHRICHT the "längliches organ."

The "languet" (Plate XVI. fig. 5) is a long tongue-shaped or conical process, fixed by its base to the ventral surface of the respiratory cavity where this is joined by the anterior extremity of the gill, and for the rest of its extent floating freely in the respiratory cavity: it is curved so as to be convex anteriorly and concave posteriorly, and its anterior surface is marked by a shallow vertical groove; at the base this groove is wider, and where it becomes continuous with the surface of the respiratory cavity, it presents a narrow median slit, which leads into a small purse-shaped cavity, flattened from side to side and richly ciliated within, Plate XVI. fig. 5 *w*.

The posterior contour of this ciliated fossa is formed by a delicate thickened band or filament, much more distinct in some other species than in the present.

It would appear probable that the languet and the ciliated fossa subserve in some manner the performance of the gustatory function.

17. From each side of the base of the languet a narrow "ciliated band" (x) runs upwards, until it meets with its fellow of the opposite side, the two thus encircling the anterior aperture of the respiratory cavity.

18. The dorsal wall of the respiratory cavity is marked by two longitudinal folds, running from before backwards to the mouth. These are the dorsal folds of Savigny and others; but there is an organ to which the name of "Endostyle" may be given (c), very distinct from these, and yet which has been invariably confounded with them, consisting of a long tubular filament, with very thick strongly refracting walls, Plate XV. fig. 4 *c*. This body lies in the dorsal sinus; its anterior extremity is slightly curved downwards, somewhat pointed, and looks stronger and more developed than the posterior extremity, which is paler, more delicate and truncated. By its ventral surface this "endostyle" is attached to a ridge of the inner tunic, which rises up into the dorsal sinus.

19. It has been stated that the circulatory system consists, not of vessels with distinct parietes, but of more or less irregular sinuses. However irregular in form, the position of several of these is very constant. There is a *dorsal sinus* running along the dorsal surface and enclosing the internal shell; there is a *ventral sinus* opposite to this and containing the ganglion; there are *lateral sinuses* connecting these. Then there is the sinus in which the intestine and generative organs lie, the *peri-intestinal sinus*, and, finally, the sinus which, connecting the dorsal and ventral system of sinuses, traverses the gill and constitutes the *branchial sinus.*

These sinuses all communicate together round the œsophagus, and above and in front of this, the heart (g) is developed. The heart lying obliquely at the posterior extremity of the dorsal sinus, is not tubular, as it has been described; it forms not more than three-fifths of a tube; nor is it correct to say that it lies in a pericardium. Its true nature will be best conceived by supposing the inner surface of a sinus to have become developed for about three-fifths of its circumference into a free muscular membrane, Plate XV. fig. 9.

This membrane is exceedingly delicate, and is composed of a single layer of flat striated muscular fibrils.

20. The direction of the circulation depends entirely upon the order of contraction of the muscular fibrils of the heart. If they contract successively from behind forwards, the blood is forced in that direction; after a certain number of such contractions, they all become simultaneously, as it were, paralysed for a short period, and then they begin to contract again, but in the inverse order, and of course with an opposite effect upon the direction of the circulation.

The blood, in its alternate flux and reflux, bathes all the internal organs—the intestine, the endostyle, the brain and the generative organs, the corpuscles finding their way as they best may among the interstices. When the force of the heart diminishes, they frequently accumulate around the intestine in consequence of becoming entangled among the meshes of the areolar tissue (13.) connecting the intestine with the parietes.

21. So far, the structure of the two forms A and B has been identical; but in proceeding to examine the reproductive organs, it will be necessary to treat of each separately.

The form A is always found to possess a connected series of young forms, the so-called *Salpa* chain, encircling its visceral nucleus; the form B, on the other hand, never possesses the *Salpa* chain, but generally contains a solitary fœtus, pendent from the upper and posterior part of its respiratory cavity. It is clear therefore that in each of these forms reproduction takes place. But is the mode of reproduction in each case similar or different? Are both, processes of gemmation, or processes of sexual reproduction, or is one process of the one description, the other of the other description? To come at the solution of this question, it will be necessary to know first, the nature and relations of the chain of young in A, then the nature and relations of the solitary fœtus in B, and, finally, to trace back the development of both to their first origin.

22. *Salpa chain of* A (Plate XV. fig. 1 *h*. Plate XVI. fig. 1. Plate XV. fig. 9). The chain is formed of a double series of fœtuses, commencing on the right side of the nucleus, curving under it, then turning upwards and over it to the right side, and finally terminating in the middle line by a free extremity midway between the two long posterior horns.

The chain is enclosed in a proper cavity, hollowed out in the substance of the outer tunic, and this sometimes opens externally opposite the free extremity of the chain, Plate XV. fig. 9.

23. The fœtuses do not form a chain by mere apposition; they are all attached by pairs to one side of a cylindrical double-walled tube, which is connected, at its anterior or proximal extremity, with the system of sinuses of the parent, to the right of the heart. The tube is in fact merely a diverticulum of the sinus system, Plate XV. fig. 9, and the blood contained in the sinuses passes freely into it. It is divided by a partition (*y*) into two canals, which are distinct for the whole length of the tube, except at its very extremity, where they communicate just as the two scalæ of the cochlea do; and it thence happens, that in the living animal, a constant current passes upon one side of the partition and down on the other, the direction of the two currents being generally, but not always, reversed with the reversal of the general circulation.

If the fœtuses be traced back upon this tube, it will be found that towards the proximal end of the tube they lose their distinctive form and become mere buds, processes of its wall, Plate XV. fig. 9. Itmay thence be conveniently termed the "gemmiferous tube."

24. The proximal extremity of the gemmiferous tube is simply transversely striated,

Plate XV. fig. 9; further on, two elevations become apparent on either side of the median line in each of these striæ. These elevations are rudiments, the inner, of the nucleus, the outer, of the ganglion of a fœtal *Salpa*. Still more towards the distal end of the tube, the young *Salpæ* are much larger in proportion to the tube; the internal organs become marked, the heart becomes visible by its contractions, and the body itself, although the respiratory apertures are as yet only marked out, not open, contracts occasionally. Finally, the otolithes make their appearance, the body becomes larger relatively to the nucleus and ganglion, and the respiratory orifices open, Plate XVI. figs. 1, 2.

25. The cavity of the gemmiferous tube communicates with the dorsal sinus system of the fœtus. Apparently the inner canal communicates by two canals, a wider and a narrower (Plate XVI. fig. 1), with the anterior portion of the dorsal sinuses of the fœtus, and the outer canal communicates with the middle of the dorsal sinuses of the fœtus. However this may be, it is quite easy to watch the blood-corpuscles of the parent making their way from the gemmiferous tube into and out of the sinus system of the fœtuses. The writer has seen one of the large blood-corpuscles of the parent entangled in the heart (which was not more than $\frac{1}{500}$th of an inch long) of a very young fœtus.

It is not exactly true that *a gradual* series in the development of the fœtuses is to be traced along the gemmiferous tube. The tube is rather marked out into sharply-defined lengths (generally three in number), in each of which the fœtuses are nearly at the same stage of growth, while they are much further developed than in the "length" on the proximal side, much less advanced than in the "length" on the distal side.

26. In this species the young *Salpæ* thus produced were extruded, when fully developed, from the aperture mentioned in (22.); but it rarely happened that even two or three adhered together, and they never formed the remarkable free-swimming chain of other species. Generally they were found solitary, presenting only on their lateral faces traces of their former adhesion. Those which were connected adhered together in a single series, the left antero-lateral extremity of the one being applied to the right postero-lateral extremity of the other; and when they became free the traces of the connection were visible as angular processes of the sinus system.

It is not correct to say that the *Salpa* chains have organs of attachment. At first they are attached by the whole length of their lateral faces, the sinus system of one being continuous by a wide channel with the sinus system of the other; but as they grow these communicating channels become more and more narrowed until they are mere points of connection; all communication then ceases, and the *Salpæ* become free from one another and move about independently.

27. Having thus determined the nature and relations of the *Salpa* chain, it remains only to be said, that the young when freed, have a sub-ovoid, posteriorly-pointed form, five muscular bands, facetted sides, and in short are identical in form, and ultimately

in size, with the form described as *Salpa* B. One-half therefore of Chamisso's theory is clearly correct; *the solitary* Salpa (Salpa A) *produces the aggregate form* (Salpa B); and we may add, that this takes place by a *process of gemmation from the walls of a tube in free communication with the circulatory system of the parent.*

28. *Solitary Fœtus of Salpa* B.—Whilst this form still forms part of the chain or is but just freed, it is sure to contain a solitary fœtus; and frequently one may be found in it when it has attained its full size, but as often not.

When the solitary fœtus exists, it hangs freely in the respiratory cavity (Plate XV. figs. 4, 8) by means of a pedicle attached to the upper and posterior part of its wall, on the left side of the mouth of the parent. In its youngest and most rudimentary state it is a somewhat conical papilla (Plate XV. fig. 7) or bulging of the inner tunic, consisting of an inner oval or pyriform cellular mass, enveloped in a delicate transparent membrane, which appears to be a continuation of the inner tunic.

As development proceeds the inner mass becomes divided into two portions, a larger turned towards the respiratory cavity, and which projects more and more into it, and a smaller subspherical, turned towards and lying in the cavity of the sinus, and bathed by the parental blood.

29. The whole mass goes on enlarging, but the former portion faster than the latter. The former becomes somewhat ovate, with its long diameter in the same direction as the long diameter of the parent, and gradually assumes the form of a *Salpa*. The muscular bands, the gill, the ganglion and its otolithic sac become distinct, and eventually the heart is obviously seen pulsating close behind the pedicle of attachment, Plate XVI. fig. 6.

In the meanwhile the smaller subspherical mass has undergone a remarkable change. It has likewise become thrust from the sinus towards the respiratory cavity, so that it no longer lies in the former, but is situated in the thick pedicle of the young *Salpa*.

It has furthermore become hollow, and contains two perfectly distinct cavities or sacs; of these the outer is concave and cup-shaped and envelopes the inner, which is subspherical, Plate XVI. fig. 6 *m*. Now the outer sac is in free communication by a narrower neck, divided into two channels by a partition, with the dorsal sinus of the fœtus; and the inner sac is in equally free communication by a neck similarly divided, with a short sinus arising immediately behind the heart; and as there is no communication between the two sacs, it follows that the current of blood in each is perfectly distinct from and independent of, that in the other. A more beautiful sight indeed can hardly be offered to the eye of the microscopic observer than the circulation in this organ. The blood-corpuscles of the parent may be readily traced entering the inner sac on one side of the partition, coursing round it, and finally re-entering the parental circulation on the other side of the partition; while the fœtal blood-corpuscles, of a different size from those of the parent, enter the outer sac, circulate round it at a different rate, and leave it to enter into the general circulation in the dorsal sinus.

More obvious still does the independence of the two circulations become when the circulation of either mother or fœtus is reversed.

30. Whether this body perform the function or not, it can hardly be wrong to give it the name of a placenta. It is identical in structure with a single villus contained in a single venous cell of the mammalian placenta, except that in the Salpian placenta the villus belongs to the parent, the cell to the fœtus; the reverse obtaining in the Mammalia.

As the young *Salpa* increases in size, the placenta, ceasing to grow, becomes proportionately smaller, until the pedicle gradually narrowing the communication with the parent ceases and the fœtus becomes free, Plate XVI. fig. 3. The remains of the placenta are traceable for some time as a small diverticulum of the dorsal sinus of the young *Salpa*, Plate XVI. fig. 3 *m*.

31. The latter as it grows nowise resembles its parent. It has a prismatic form, has seven muscular bands, and developes processes from its posterior extremity. It becomes indeed perfectly similar to the form which has been described as *Salpa* A.

It thence appears that the other half of Chamisso's theory is also perfectly true, viz. *the aggregate form of* Salpa (Salpa B) *produces the solitary form* (*Salpa* A), and the circulatory system of the fœtus in this case is connected with that of the parent, *not immediately, but by means of a very distinct and well-developed placenta.*

Here is one very clear distinction between the two processes of reproduction. Are there any other differences? To answer this question we must proceed to trace back both processes to their origin.

32. It has been seen that the young *Salpæ* B are developed by a process of gemmation from the gemmiferous tube of *Salpa* A. Whence comes the tube itself?

The smaller the individual of the form A examined, the shorter is the gemmiferous tube, and the less developed the buds upon it. In individuals just free, or about to be free, it is a very short cylindrical tube, arising on the right side and just in front of the heart, and curving downwards and backwards, Plate XVI. figs 3, 3 *a*.

In still smaller attached specimens it appears as a very short, somewhat conical process (imperfectly divided by a partition) of the dorsal sinus, close to the heart; its walls are smooth, and the blood-corpuscles are easily seen passing up one side and down the other of the partition, Plate XVI. fig. 4.

It is clear therefore that the gemmiferous tube is nothing more than a stolon, containing a diverticulum of the circulatory system of the parent, and the whole process of reproduction as it is manifested in *Salpa* A is one of gemmation. *Salpa* B *is a bud of Salpa* A.

33. Following the same course of investigation with regard to the young *Salpa* A (which it has been seen is produced from *Salpa* B), it is found, that in *Salpæ* B, which are either still adherent to the gemmiferous tube or just set free, there is no protuberance of the inner tunic into the respiratory cavity; but where this afterwards exists, a pedicle of greater or less length is attached, and running backwards, carries

at its extremity an oval cellular mass, Plate XVI. fig. 8. This hangs suspended by its pedicle in the cavity of the sinus, and is freely bathed by the blood. In one specimen the length of the pedicle was $\frac{1}{250}$th of an inch, the long diameter of the oval body about $\frac{1}{600}$th of an inch.

In still younger forms of the *Salpa* B., and indeed as soon as the separate organs are distinguishable, the outer tunic bulges slightly in the middle line behind the outline of the posterior aperture and beneath the nucleus, Plate XVI. figs. 1, 2; this protuberance is caused by the presence of a spherical body (q) about $\frac{1}{1000}$th of an inch in diameter, containing a clear vesicle $\frac{1}{1700}$th of an inch in diameter, which again frequently contained a round opake spot or nucleus about $\frac{1}{8000}$th of an inch in diameter; the latter sometimes appeared as a thick-walled vesicle. This is plainly an ovum; a narrow pedicle (q') is attached to its upper extremity and runs upwards, curving slightly forwards to the same point as in the preceding forms.

It would appear then that the *Salpa* B developes a single ovum, which is at first placed in the median line in the ventral sinus; that partly by the increase in size of the body, and partly in consequence of a shortening of its pedicle which acts as a gubernaculum, it becomes drawn from this position upwards and to the left side; and that in the meanwhile, probably in consequence of fecundation, it becomes altered in structure, and precisely similar to and identical with the cellular mass which has been seen to form the rudiment of the young *Salpa* A, Plate XVI. fig. 7. In this case *the* Salpa A *would be a true embryo developed by a process of sexual generation.*

34. Sexual generation however presupposes a male fecundating organ, and this is found in *Salpa* B as a ramified body, hitherto generally called a liver (p), Plate XV. figs. 6 and 7, closely surrounding the intestinal canal with a network, solid in the younger form, but in the older tubular, with very thin walls, and containing a vast number of pale-greenish circular cells, from $\frac{1}{5000}$th to $\frac{1}{1700}$th of an inch in diameter; and besides these detached spermatozoa, with very thin tails and long narrow heads, about $\frac{1}{1600}$th of an inch in length. The testis had no visible excretory organ, but such might well escape notice.

Nothing at all resembling this body is found in the form A; its contents sufficiently demonstrate its real nature, and its existence on the other hand is strong confirmatory evidence, if any be needed, that the pediculate body described above is a true ovum.

One curious circumstance needs to be remarked; the testis does not develope *pari passu* with the ovum and attain its full development at the same time, as might be imagined. The testis is always behind the ovum in its progress, and does not, indeed, seem to have attained its full development until the latter has become freed from the parent.

Without carefully tracing the form B through all its stages, it might readily be supposed to be always male; in fact, fully-grown specimens, while they always possess a well-developed testis, rarely contain any embryo, this being generally set free when the parent is about half or two-thirds grown. The careful observer will, however, be always able to detect a trace of its former attachment, in a sort of cicatrix, left at the corresponding part of the respiratory chamber.

35. It is not clear by what channel fecundation takes place, whether each *Salpa* B impregnates its own ovum by discharging the contents of its own testis into the circulatory fluid, which would be a procedure altogether anomalous; or whether, on the other hand, impregnation do not rather take place from without, a presumption which is strengthened by analogy, and by the fact, that the testis does not seem to attain maturity early enough to fecundate its own ovum. The spermatic fluid may have access to the ovum by the gubernaculum becoming hollow and tubular, as will be seen to be the case in the *Pyrosomata*, and indications of such an occurrence have occasionally manifested themselves.

36. To recapitulate.—The form A (*Salpa solitaria*) produces a stolon, from which, by gemmation, arises the form B (*Salpa gregata*). This contains a testis and a single ovum attached by a pedicle or "gubernaculum" to the wall of the respiratory chamber. Fecundation takes place in a manner not yet clearly ascertained, and the "gubernaculum" shortens until the ovum is brought into close contact with the respiratory wall or inner tunic. The latter then protrudes into the respiratory canal, enveloping the ovum in a close sac; the ovum becomes developed into an embryo, which is connected by a genuine placenta with its parent, and ultimately assuming the form of *Salpa* A becomes detached and free.

37. While Chamisso's formula, then, expressed the truth with regard to the generation of the *Salpæ*, it did not express the whole truth.

True it is, that the *Salpa solitaria* always produces the *Salpa gregata*, and the *Salpa gregata* the *Salpa solitaria*; but it is most important to remember that the word "produce" here means something very different in the one case, from what it means in the other. In the *Salpa solitaria* the thing produced is *a bud*; in the *Salpa gregata a true embryo*. There is no "alternation of generations," if by generation sexual generation be meant; but there is an *alternation of true sexual generation with the altogether distinct process of gemmation.*

It would be irrelevant to discuss here the wide question of the "alternation of generations" in all its bearings; but the writer may be permitted to express his belief, founded upon many observations upon the Polypes, Acalephæ, &c., that the phenomena classed under this name are always of the same nature as in the *Salpæ*; that under no circumstances are two forms alternately developed by *sexual generation*; but that wherever the so-called "alternation of generations" occurs it is *an alternation of generation with gemmation.*

38. Using the terminology of insect metamorphosis, as Chamisso has done (70.), the larva never produces the imago by sexual generation, the imago again producing the larva by sexual generation. But a pseud-imago, which is indeed nothing more,

homologically, *than a highly individualized generative organ,* is developed from the larva, ova are produced by it, and from these the larva again is developed; the whole process differing from that common to animals in general, in nothing but the independence and apparent individuality of the generative organ.

39. It cannot be too carefully borne in mind that zoological individuality is very different from metaphysical individuality, and that the whole question of the propriety of the "alternation theory" as a means of colligating the facts (for at best it can be nothing more) turns upon the nature and amount of this difference.

If the true definition of the zoological individual be (as the writer believes it to be) "the sum of the phenomena successively manifested by, and proceeding from, a single ovum, whether these phenomena be invariably collocated in one point of space or distributed over many," then there is no essential difference between the reproductive processes in the higher and lower animals, and the alternation theory becomes unnecessary.

In accordance with this definition, neither the form A, nor the form B would be a zoological individual; not either of their forms, but both together, answer to the "individual" among the higher animals.

In strictness both *Salpa* B and *Salpa* A are only parts of individuals,—are organs; but as we are unaccustomed to associate so much independence and completeness of organization with a mere organ, to give them such a name would sound paradoxical. It is proposed therefore to call them, and all pseudo-individual form resembling them, "zoöids," bearing in mind always that while the distinction between zoöid and individual is real, and founded upon the surest zoological basis,—a fact of development,—that between zoöid and organ is purely conventional, and established for the sake of convenience merely*.

40. In the *Salpæ,* then, the parent and the offspring are not dissimilar, but the individual is composed of two zoöids.

In *Cyanea,* the individual is composed of two "zoöids," a medusiform and a polypiform zoöid.

In the *Trematoda* there are frequently three "zoöid" forms to the individual.

In the Aphidæ the sum of from nine to eleven "zoöids" composes the individual, the great number of zoöid forms in this case being simply an instance of that "irrelative repetition" of parts so common among the lower animals.

A similar irrelative repetition exists among the so-called "compound" animals, the Polypes and compound Ascidians; and consistently with the present theory we must call a *Sertularia* or a *Pyrosoma,* for instance, not an aggregation of individuals into a common mass, but an individual which is developed into a greater or less number of zoöid forms, which in the present case remain united.

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* For a further consideration of this subject the author begs to refer to Dr. CARPENTER's "Principles of Physiology," in which the whole question of individuality in plants and animals is treated in a very clear and masterly manner; to Mr. THWAITES's papers in the Annals of Natural History; and to an attempt to apply the principles advocated in the text to the metamorphosis of the Echinoderms in a Report by himself.—*Annals,* July 1851.

Thus the stem and branches of the polypidom in *Sertularia* are "organs," the ovarian vesicles are "organs," the polypes are "zoöids;" the sum of the organs and zoöids constitutes the individual.

If the separate polypes be individuals, what is the polypidom which exists before them, and therefore cannot be derived from them?

It seems startling to assert that a *Salpa* of the form A with some fifty or sixty of the form B which proceed from it, constitutes but one zoological individual; still more to aver this of some millions of Aphides all proceeding indirectly from one ovum; but these difficulties have reference merely to our ordinary notion of individuality, and involve us in no self-contradictions and inconsistencies such as seem inherent in any other view of the case.

SECTION II.—*The Anatomy of* Pyrosoma.

41. This genus, first established and very imperfectly described by PERON[*], received elaborate investigation from LESUEUR[†] and from SAVIGNY[‡], who very carefully described every part of its organization with the exception of the generative organs, and one or two other points of minor importance.

Subsequently M. MILNE-EDWARDS[§] showed that the nature of the circulation was the same in it as in the other Ascidians.

Of the three species distinguished by LESUEUR the present appears most closely to resemble the *P. atlanticum*.

42. The only specimen of this remarkable animal which the writer has had an opportunity of examining in the fresh state, was procured on the night of the 15th of June 1850, in about 45°·85 S. lat. and 110°·30 W. long. The sky was clear but moonless, and the sea calm; and a more beautiful sight can hardly be imagined than that presented from the decks of the ship as she drifted, hour after hour, through this shoal of miniature pillars of fire gleaming out of the dark sea, with an ever-waning, ever-brightening, soft bluish light, as far as the eye could reach on every side. The *Pyrosomata* floated deep, and it was with difficulty that some were procured for examination and placed in a bucketfull of sea-water. The phosphorescence was intermittent, periods of darkness alternating with periods of brilliancy. The light commenced in one spot, apparently on the body of one of the "zoöids," and gradually spread from this as a centre in all directions; then the whole was lighted up; it remained brilliant for a few seconds, and then gradually faded and died away, until the whole mass was dark again. Friction at any point induces the light at that point, and from thence the phosphorescence spreads over the whole, while the

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[*] Annales du Museum, 1804.

[†] Journal de Physique, 1815.

[‡] Mem. sur les Animaux sans Vertèbres.

[§] Comptes Rendus, 1840.

creature is quite freshly taken; afterwards, the illumination arising from friction is only local.

43. So far as could be observed the *Pyrosoma* had no power of locomotion; any such power arising from a contraction of the hollow cylinder is out of the question, as its substance is cartilaginous and non-contractile. Any one who does not examine these animals quite closely may be readily deceived on this point; for the alternate fading and brightening of the phosphorescent light gives rise to the impression that the creature recedes from and approaches the eye; and viewing them from the deck of a ship only, it is difficult to imagine that they do not really move with some rapidity*.

44. The *Pyrosoma* may be described as a hollow cylinder, solid and hard to the touch, closed and rounded at one end, open at the other. A narrow lip projects inwards at the open extremity; it has been called a membranous diaphragm, but in the specimen examined it was certainly cartilaginous and immoveable, like the rest of the animal. The thickness of the wall of the cylinder was about two-fifths of an inch; its diameter was about 1 inch and a half; its length was about 10 inches. The outer surface of the cylinder was covered with a multitude of small projections, and close to them opened small circular apertures. The inner surface of the cylinder was uneven but not rough, and was similarly pierced with circular apertures.

The wall of the cylinder consists of a vast number of minute Ascidian "zoöids" lying perpendicular to the axis of the tube, and united together by a common cartilaginous basis; and the small circular apertures correspond respectively, the outer to the anterior aperture of the *Salpa*, the inner to the posterior aperture.

Each aperture is provided with a small dentated membranous valve, Plate XVII. fig. 1.

45. In each zoöid there is at one point a ganglion (*d*), with a mass of deep red otolithes. As in *Salpa*, this must be called the ventral side; the opposite is the dorsal side, and contains (as in *Salpa*) an endostyle, Plate XVII. figs. 1, 2 *c*. The ganglionic or ventral surfaces of all the polypes are turned the same way, and towards the open end of the cylinder.

By far the greater part of the space occupied by each zoöid is taken up by the respiratory cavity. This is elliptical, and compressed laterally. It is lined by the proper branchial network, hereafter to be described (*v*), and communicates freely by means of the apertures in the branchial network with the post-branchial or anal cavity, which, as before stated, opens into the interior of the cylinder.

46. The viscera lie behind the branchiæ. They consist of the digestive canal, heart, and generative organs.

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* My observations upon the power of locomotion of *Pyrosoma* were very imperfect, as I was anxious rather to attend to the more interesting points of structure. Certainly the cylinder does not contract as a whole, but it is very possible that the zöoids do, and so move by the reaction of the forced-out water against the closed end of the cylinder.

The intestine (*r*, *s*, *t*) commences by a wide mouth with thick lips, at the posterior, ventral extremity of the respiratory cavity. The œsophagus (*r*) runs back, and then upwards to terminate in the wide subquadrilateral stomach (*t*). A narrow pylorus communicates with the intestine, which passes at first upwards and forwards, and then suddenly becoming bent upon itself, runs downwards and to the right side, to end in the wide flattened anus (*r*).

The œsophagus is dotted over with branched carmine pigment-cells; and similar cells are frequently seen upon the intestine just beyond the pylorus.

47. A tubular axis (*u*) arises from the stomach, and branches out on the rectum into a system of tubes as in *Salpa*; but the ramifications are less numerous and less regular, with wider meshes than in the latter. The tubes are less transparent and have more the appearance of solid fibres, and finally they terminate towards the anus in wide globular cæca.

The stem of this system is about $\frac{1}{1200}$th of an inch in diameter.

48. Each zoöid is composed of two tunics, an outer (α), confluent with the general cartilaginous basis, and an inner (β), continuous with the outer at its anterior and posterior extremities, and adherent to it antero-laterally, in two oval spots, one on each side, which, when examined by the microscope, appeared to consist of nothing more than an aggregation of clear circular cells about $\frac{1}{800}$th of an inch in diameter. (δ). These were considered by SAVIGNY to be the ovaria, but they have not the appropriate structure, and it will be seen that the ova are formed elsewhere.

In all the rest of their extent the inner and outer tunics are separated by a very obvious space. This is one large vascular sinus, and the viscera lie in it and are bathed by the blood which fills it.

The heart (*g*) is placed on the dorsal side just behind the posterior extremity of the internal shell. In structure it perfectly resembles that of *Salpa*, and its contractions are reversed in a similar manner. No distinct vessels were to be traced in these animals.

49. The endostyle (*c*) resembles that of *Salpa* in its structure. It is as long as the branchial chamber, and lies in the dorsal sinus, supported by a projecting ridge of the inner tunic. On each side of it below, there is a longitudinal thickening, which readily gives rise to the appearance of four dorsal bands or "undulated vessels," described by SAVIGNY.

50. The branchiæ (*v*) are symmetrical, one on each side, and are composed of a network formed by longitudinal and vertical bars or laminæ.

The vertical bars are outside; the longitudinal bars are at equal distances along their inner surface, and are attached at the point of intersection.

The vertical bars are attached to the inner tunic at their upper and lower extremities; for the rest of their extent they are free.

The longitudinal bars (*v*, fig. 3) are rather laminæ, flattened horizontally, slightly thickened at their free edges, and beset along the upper surface of these edges with small teeth; they project anteriorly and posteriorly beyond the vertical bars.

Both systems of bars appeared to be tubular, although no corpuscles were seen moving in them, and the edges of the vertical sinus were thickly covered with long cilia, moving in opposite directions on the opposite sides.

51. The dorsal edges of the two branchiæ were separated by a space containing the thickened dorsal folds already mentioned, and this is continuous posteriorly with a band which connects the mouth with the dorsal surface of the respiratory cavity, and allows the water to pass back on each side of it to the post-branchial cavity.

52. Anteriorly on the ventral side is an organ (fig. 10 *w*) analogous to the "ciliated fossa" of the *Salpæ*, and behind this a series of tongue-shaped eminences (fig. 1 *f*) projects into the respiratory cavity, analogous to the "languet" of the *Salpæ*.

The "ciliated fossa" is compressed laterally, and placed upon the upper surface of a protuberance, formed by the ventral wall of the respiratory cavity in the middle line. On each side a flattened ciliated band (fig. 10 *x*) runs up on the respiratory wall in front of the anterior edge of the branchiæ, and meets above with its fellow of the opposite side.

The "languets" are altogether eight in number. They extend in a longitudinal series between the ciliated fossa and the mouth. They are all slightly excavated and ciliated anteriorly.

53. Immediately beneath the ciliated fossa, and in the midst of the ventral sinus, lies the ganglion. This is about $\frac{1}{146}$th of an inch long, somewhat egg-shaped, with its large end forwards. Its posterior extremity is in contact with a mass of deep red otolithes, fig. 10 *d*.

A small nerve runs from the ganglion to the lateral ciliated band. Five or six branches are distributed to the anterior aperture, and two principal branches run backwards to the posterior aperture, giving off branches to the mouth in their course.

54. The *Pyrosomata* are hermaphrodite.

The testis (*p*) is the so-called "hepatic organ" of LESUEUR, SAVIGNY and PERON. It consists of ten, twelve, or more cæca, connected by their posterior extremities, and here joining a central duct, which opens by a papilla at the upper and posterior part of the respiratory cavity. The spermatic sacs lie loosely in a dilatation of the vascular sinus, and are bathed freely by the blood.

Each sac is delicate and thin-walled, about $\frac{1}{500}$th of an inch in diameter, and very variable in length. In adult specimens the distal or anterior end of each sac is filled with a pale cellular mass. Towards the attached end this becomes darker and more distinctly granulous, and the filiform bodies of masses of spermatozoa are plainly perceived.

The spermatozoa have narrow elongated heads and very long delicate tails.

55. There cannot be said to be any ovary properly so called. But to the left, and

rather in front of the testis (fig. 5), there could always be found more or less decided traces of one or more ova.

Commonly there was a single ovum (figs. 4–6), measuring about $\frac{1}{230}$th of an inch in diameter, with a clear germinal vesicle $\frac{1}{600}$th of an inch in diameter, and a vesicular thick-walled germinal spot $\frac{1}{1600}$th of an inch in diameter.

The ovum is inclosed in a strong transparent sac, continuous with a pedicle or gubernaculum (fig. 6 q'), which runs to the upper and posterior part of the inner tunic on the left side, and there terminates in a papilla, like that of the vas deferens, projecting into the post-branchial cavity.

In young specimens, when the ovum is small and the yelk pale, this gubernaculum frequently appears to be solid; but in fully-grown specimens, when the ovum has its full size, and the yelk is darker and granulous, it presents the appearance of a wide tube, especially at its upper part. And here there was frequently an appearance of dark striæ and moving granules, prompting the belief that spermatozoa had travelled thus far.

In one instance (fig. 6) the sac of the ovum was empty and the gubernaculum or duct widely distended. The appearance of spermatozoa in the duct was here very strong, fig. 5.

None of the compound ova described by Savigny were present in the specimens of *Pyrosoma* examined.

56. The young polypes described by Savigny as existing between the fully-formed ones, in all stages of development, are formed by gemmation, Plate XVII. fig. 7 *q*.

A diverticulum of the dorsal sinus of the parent is formed just above the heart; the extremity of this diverticulum thickens and enlarges, and assumes the form of a single zoöid. For a long time a vascular connection is maintained between it and the parent, by means of a duct, in which there seemed to be traces of a longitudinal partition, as in the gemmiferous tube of *Salpa*. Ultimately the connection appears to cease, and the two polypes live on independently.

It is to be remarked, that while in *Salpa* the ventral side of the young bud is first marked out, and the communication of the parent with the young is thence on the dorsal side of the fœtus, in *Pyrosoma* the dorsal side is first developed, and the communicating canal opens on the ventral side of the young.

57. The ovum or ova, for there are sometimes two or three, are perceptible very early in the young polype produced by gemmation, and are then situated in the middle line posteriorly.

58. The muscular system is best seen in a young specimen (fig. 8 *k*). Two very delicate bands encircle the inner tunic anterior to the ganglion. From the posterior extremity of the ganglion two strong bands arise, which diverge for about half the distance between the ganglion and the mouth. Here they divide into two branches, one of which continues the original direction, while the other meets its fellow just behind the mouth. The former, as it leaves the under surface to become lateral, is

much increased in size, and eventually terminates at a short distance from the generative glands, forming on each side the band of which SAVIGNY speaks as passing towards the liver.

Midway between the ganglion and the point of division, the diverging bands give off each a thin band, which runs to the lateral oval cellular masses.

SECTION III.—*The Homology of Structure of* Salpa *and* Pyrosoma, *and of these with the ordinary Ascidians.*

59. It seems to have been pretty generally admitted by naturalists, that the *Tunicata* are susceptible of division into two great classes, the Monochitonida and Dichitonida, characterized by certain differences in the structure of the branchiæ and in the degree of adhesion of the inner and outer tunics.

Of the two species whose structure has been described, *Salpa and Pyrosoma,* the former was placed among the Monochitonida (or "those having the inner sac adherent throughout to the outer tunic"), while the latter was reckoned among the Dichitonida (or those "whose inner sac is adherent to the outer tunic, at its two orifices, only").

Now there is an ambiguity which must be noticed here at starting, as it is one which has caused much confusion, and must, unless cleared up, cause our conception of the real structure of the Ascidians to be very indistinct. Authors speak of the greater or less adherence of the outer and inner sacs, and consider the "outer sac" of the ordinary Ascidian to be homologous with the outer tunic of the *Salpa.* The "inner sac," again, is with them homologous with the inner tunic of the *Salpa.* But it is not so; every Ascidian, as M. MILNE-EDWARDS has clearly shown in *Clavelina,* consists of three tunics: an outer, the *test*; a middle, which is here called outer *tunic*; and an inner, the inner *tunic.* The inner tunic of the *Salpa* answers to the inner tunic of *Clavelina,* but its outer tunic answers to the test and the outer *tunic* together (90.)*.

However, with regard to the two genera in question, whatever be the nature of the two membranes of which they are composed, there is absolutely no distinction whatever to be drawn between them. The inner membrane is just as much or as little adherent to the outer in *Pyrosoma* as in *Salpa.* In each case the wide sinuses between the two membranes form the sole vascular system.

60. It may be said that there is an essential difference between *Salpa* and *Pyro-*

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* This essential difference between the test and the two *tunics* of the Ascidians has its origin in the embryo. The tunics are formed by the ordinary process of development, while the test having a totally different chemical composition, is in a manner secreted round, and envelopes the whole embryo.

There seems to be a certain independence in the mode of growth of the embryo and that of the test, the former lying at first quite free in the latter; and it appears to depend entirely upon the relative rates of growth of the two whether the resulting Ascidian shall be Monochitonidous or Dichitonidous.

The test of the Ascidian composed of cellulose is every way homologous with the test of the Mollusk composed of carbonate of lime.

soma in the structure of the branchiæ. A little consideration, however, will show that this is merely a difference in degree.

Savigny has shown that in certain *Salpæ* there is an upper division of the "gill," an "epipharyngeal band" (to carry out the nomenclature adopted at (10.)), as well as a hypopharyngeal band.

Now in the genus *Doliolum* (88.)* this epipharyngeal band has attained a much greater development (though the mouth still remains at the upper part of the cavity), and like the hypopharyngeal band carries a number of ciliated branchial bars. These bars have a direction more or less parallel to those carried by the hypopharyngeal band, and hence there appear to be two branchiæ, an upper and a lower†.

But in *Pyrosoma* the mouth is on the ventral side of the animal; the epipharyngeal band, developed in proportion to the distance of the mouth from its normal position, takes a direction at right angles to the axis, and thence comes to carry the branchial bars belonging to it parallel to the axis; while the hypopharyngeal band carrying its branchial bars as before, the two sets cross and produce the branchial network.

The line between the Monochitonida and Dichitonida then can certainly not be drawn between the *Salpæ* and *Pyrosomata*.

61. The *Pyrosomata*, in the main, have the closest similarity in structure to the Botryllidæ and other compound Ascidians; but in these latter, the separation between the test and the outer tunic becomes more and more marked, until it attains its greatest amount in the Clavelinidæ, Cynthiæ, &c.

Now does this separation furnish a character of any value or importance, systematically? Surely not, for the value of a character depends upon the number of differences of which it is a mark; and this is the mark of none.

Savigny observed the close resemblance between *Botryllus* and *Pyrosoma*, which yet differ in this character.

Clavelina and *Perophora* are acknowledged to be closely allied genera, and yet in the former the test and outer tunic are separated to their utmost extent; in the latter‡ they are as closely united as in any *Salpa*.

In the Cynthiæ the test and tunics are generally very distinct; but in *Cynthia ampulloides*, judging by the descriptions of Van Beneden, they are confounded together§.

Again, in the *Salpa vaginata* of Chamisso, the test makes its appearance as a separate structure, and the cavity in which the gemmiferous tube lies in all the *Salpæ*, and through which it makes its way to the exterior, seems to represent the normal separation of the test and tunics.

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* And it may be added in the genus *Anchinaia*, described in Wiegmann's Archiv for 1833, which seems to be a most interesting transition form between the *Salpæ* and *Doliolum*, if indeed it be not the young form of *Doliolum caudatum* itself.

† See also on the homology of the branchial organs of the *Salpæ* and ordinary *Tunicata*, M. Milne-Edwards, Sur les Ascidies composées, p. 55.

‡ See the very beautiful figures and descriptions of Lister in the Philosophical Transactions for 1834.

§ Mém. de l'Acad. Roy. de Bruxelles, tome xx.

The homology of the cellulose test of the Ascidian with the calcareous test of the Mollusk has already been adverted to; and it would seem that the separation of the former from the tunics, or its confusion with it, is of as little value as a character among the *Tunicata,* as the imbedding of the shell in the mantle in *Limax* would be in separating it from *Helix,* whose shell is distinct from the mantle.

62. It would appear, indeed, that in no natural family is it less possible to draw any very broad line of demarcation among the various members than in the *Tunicata.*

Tracing them one by one, we find that all the organs of the *Salpæ* have their homologues among the other Ascidians; the various genera passing one into the other by almost imperceptible gradations.

Even the connection of the fœtus with the parent by a placenta, a feature apparently so unique in the *Salpæ,* seems to be not without its analogue in the Didemnidæ*.

The actual fact of a placental circulation indeed has not been observed, but it may be surmised, as M. MILNE-EDWARDS† has observed the ova to be developed within a diverticulum of the vascular system of the parent.

The peculiarly formed heart, the circulation without distinct vessels, and the reversal of its direction are common to all *Tunicata.*

63. In all the *Tunicata,* again, it would seem that the first bend of the intestine (whatever its subsequent course) is dorsal, *i. e.* to the side opposite the ganglion, and almost always to the right side. *Doliolum,* however, seems to be a sinistral *Tunicate.*

What has been described in the present paper as the "Tubular System" was found by LISTER (Philosophical Transactions, 1834) in *Perophora,* and described by him as "transparent vessels that may be supposed lacteals."

In *Chelyosoma* there is a mass of otolithes and a fossa, seemingly analogous to the "ciliated fossa."

The "languet" of the *Salpa* has its homologues in *Pyrosoma, Chelyosoma* and *Clavelina,* and is represented by smaller tentacular filaments in *Cynthia, Diazona, Synoicum* and *Polyclinum.*

64. All the *Tunicata* are hermaphrodite; and from the small size of the only efferent

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* The only remaining important difference of *Salpa* from its congeners consists in the *Salpa* larvæ being tailless, while, as the beautiful researches of M. MILNE-EDWARDS have shown, the other Ascidian larvæ have tails. This exception, however, is singularly paralleled among the Amphibia. The larvæ of the ordinary Amphibia have, as is well known, deciduous tails like the ordinary Ascidians. *In the genus* Pipa, *however, which carries its young in cells upon its back, the larva is tailless.* (LEUCKART, Ueber Metamorphose, &c. SIEBOLD and KÖLLIKER's Zeitschrift für Wissenschaftliche Zoologie, 1851.) Such a very striking analogy needs no comment.

† Obs. sur les Ascidies composées, p. 23.

generative duct in the Botryllidæ, it would seem that the ova make their exit in the same way as in the *Salpæ*.

All the *Tunicata* possess the power of gemmation, and the buds are always formed as in *Salpa* (though not always with the same regularity), from a diverticulum of the sinus system.

65. With regard to the "endostyle," which appears hitherto to have been strangely confounded with the dorsal folds of the inner tunic, the writer can speak positively as to its existence in the *Salpæ*, *Pyrosomata* and certain Botryllidæ. In all these species it is figured by CUVIER, CHAMISSO, SAVIGNY and MILNE-EDWARDS*, but not described; and as a precisely similar structure is figured by SAVIGNY and others in the solitary Ascidians, it is not perhaps too much to assume that the endostyle exists in them also. Should such be the case, we should be furnished with a new and very remarkable distinctive character of the *Tunicata*†.

The "elæoblast" of the *Salpæ* appears to be represented in the solitary Ascidians by the calcareous mass in contact with the heart, described by VAN BENEDEN in *Cynthia ampulloides*.

66. The simple epipharyngeal and hypopharyngeal bands of the *Salpa* have been traced through their first degree of complication in *Doliolum* to *Pyrosoma* and *Botryllus*, where they form a true branchial sac, differing from that of the simple Ascidians only in the number and size of its meshes.

On the other hand, in *Pelonaia* the hypopharyngeal band itself has disappeared. It is a *Salpa* in which the oral and cloacal orifices have approximated while the "gill" has become obliterated‡.

In the strange form *Appendicularia* (79.), the simplification is carried a step further, for there is but one orifice, the oral. The anus opens on the dorsal surface, and a long appendage is added in the same position as that of *Boltenia*, but instead of being a long pedicle of attachment, it is a free and energetically moving fin.

67. To sum up what has been said, it appears that the *Salpæ* are not, as has been generally supposed, an aberrant form of the *Tunicata*, but rather that they are connected by insensible gradations with the other forms of the group; neither is there any circumstance in their two modes of multiplication at all at variance with what takes place in other genera of the family.

The distinction between monochitonidous and dichitonidous *Tunicata* cannot be kept up in its present sense, for the proper inner and outer tunics are equally adherent in all *Tunicata*; and as expressing the degree of adherence of the test to the outer tunic, the distinction is of no value, systematically, as the character may vary greatly in the same or closely allied genera.

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* LISTER, in his description of *Perophora*, *loc. cit.*, figures the endostyle and says, "along the middle of the back is a vertical compound stripe, *d* (fig. 4), that seemed to me cartilaginous."

† Since the above was written the author has had the satisfaction of finding both the endostyle and the ciliated sac, in a small, very transparent *Cynthia* (—— ? sp.) obtained at Felixstow, on the Suffolk coast.

‡ *Chelyosoma* would appear to resemble *Pelonaia* in the absence of any distinct branchial sac; but ESCHRICHT's figures are not very clear.

Section IV.—*History of our Knowledge of the* Salpæ.

68. Forskahl, the Danish naturalist, founded the genus *Salpa* upon certain animals taken in the Mediterranean. No less than eleven species are described and figured by him (and with remarkable clearness and accuracy) in his "Descriptiones Animalium," a work which he unfortunately did not live to see published, but which made its appearance in the year 1775.

The following is his definition of the genus: "Salpa corpore libero, gelatinoso, oblongo, utroque apice aperto; intus vacuo; intestino obliquo variat: *a*) nucleo globoso, opaco, juxta anum *b*) nucleo nullo sed linca dorsali opaco.

"Nomen mutuatum a Σάλπα, pisce a Græcis cognito et huic vermi additum ob similitudinem formæ cum tubo canoro. Animal plerumque gregarium; mira cohærens symmetria motum corporis per systolem et diastolem, siphonica arte perficiens."

Browne*, who appears to have been unacquainted with Forskahl's work, gave the name of *Thalia* to some *Salpæ*, which he describes and figures in the rudest manner.

Bosc seems to have been the first to suspect the identity of these two genera, a suspicion which was converted into a certainty by the researches of Cuvier, who not only disentangled the nomenclature of the genus from the confusion into which it had fallen, but gave the first accurate idea of the anatomy of the *Salpæ*, and first announced their true zoological relations.

69. Much was added piecemeal to the foundation thus laid by Cuvier, by subsequent authors. Meyen and Milne-Edwards described the nervous system, Kuhl and Von Hasselt, Eschscholtz and Milne-Edwards, announced the singular nature of the circulation. Cuvier and Chamisso hinted, and Meyen described, the placental connexion of the solitary fœtus with the parent; Eschricht and Sars declared the proximate nature and mode of origin of the *Salpa* chain.

70. Chamisso again founded the theory of the "alternation of generations," using that very phrase† to express the peculiarities accurately observed by him in the mode

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* Natural History of Jamaica, 1785.

† Justice seems to have been hardly done to Chamisso as the first promulgator of the theory of the "alternation of generations." He says at p. 10, "Qua seposita (Salpâ bicorni) *alternationem generationum* legem esse ut posuimus genericum, omnibus communem speciebus, observationibus innititur;" and at p. 3, "Talis speciei metamorphosis generationibus in Salpis duabus successivis perficitur, *forma per generationes* (*nequaquam in prole seu individuo*) *mutata*. Verum enimvero qua lege proles Salparum, ut animal ab ovo, imago a larva, inter se differunt, parum elucet." And in his interesting "Reise um die Erde," Chamisso shows still more clearly his distinct conception of the theory by the remarkable phrase, "Es ist als gebäre die Raupe den Schmetterling und der Schmetterling hinwiederum die Raupe." "It is as if the Caterpillar brought forth the Butterfly, and the Butterfly the Caterpillar."

Subsequent writers seem not to have done much more in reality than bring new cases under the law here so of multiplication of the *Salpæ*, but the nature and existence of the sexual organs remained undetermined until Krohn and Steenstrup in 1846 discovered the male organs; subsequently Krohn made out the true ovaries also.

Finally, a most accurate account (to which indeed the present memoir can be considered only as confirmatory independent testimony) of the whole course of development and reproduction of the *Salpæ* was given by Krohn in the Annales des Sciences for 1846.

71. Without undertaking the somewhat unprofitable task of giving a detailed historical account of all that has been written upon the *Salpæ*, it may be of interest to notice, with a view to reconcile, a few of the more important discrepancies among the statements of the chief investigators. And first:

Of the sides and ends of the Salpæ.—On so simple a matter as this, almost every writer has different views. Cuvier calls the ganglionic surface ventral, the opposite dorsal, the nuclear end anterior, the opposite posterior. Savigny appears to follow him. Chamisso follows Cuvier as to the anterior and posterior ends, but reverses the dorsal and ventral sides.

MM. Quoy and Gaimard give the ganglionic end as anterior, the nuclear as posterior, the nuclear side as ventral, the ganglionic as dorsal.

Meyen gives the same determination. Eschricht considers the nuclear end to be posterior, the ganglion side ventral; as also Sars.

M. Milne-Edwards seems to follow Chamisso. It is much to be wished that some uniform nomenclature could be adopted. The reasons for the terms used in the present paper have already been given (5.).

72. *The Nervous System.*—The nervous system was denied by Cuvier altogether. Savigny describes the ganglion, without recognizing its true nature, as the "tubercule qui dans les Ascidies est contigu au gros ganglion."

Chamisso describes what appears to be the thickened edge of the "ciliated fossa," and states that Eschscholtz considered it to be a nerve (*op. cit.* p. 5).

Quoy and Gaimard describe the ganglion, but omit all mention of the auditory sac.

Meyen claims the discovery of the true nervous system; but although he figures it pretty accurately, he omits all mention of the otolithic sac, and seems after all in doubt whether it may not be a respiratory organ; and it was reserved for M. Milne-Edwards to give the first satisfactory account of these structures.

Both Eschricht and Sars subsequently omit to describe the auditory sac.

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clearly expressed, and they do not always seem to have kept so clearly in mind the modest renunciation of any claim on the part of the theory to be an *explanation* of the facts, contained in the last paragraph of the former quotation.

Finally, it must not be forgotten, that though Chamisso was the first promulgator of the "alternation," he expressly (with a candour impossible to be too much commended) gives the credit of the conception to his companion Eschscholtz, "generationis Salparum primus et perspicax fuit indagator amicissimus Eschscholtz," p. 9, and again in the preface to the second fasciculus of his observations.

73. *The "Ciliated Sac" and "Languet."*—Cuvier refers to this organ in *Salpa Tilesii* as "l'anneau irregulière qui la termine (la branchie) en arrière."

It has already been mentioned that this organ is mentioned by Chamisso as a problematical nervous apparatus. Quoy and Gaimard described its thickened rib as a vessel, adding, "nous dirons un vaisseau parceque nous croyons avoir vu le sang circuler dans son intérieur," apparently mistaking the ciliary motion for a circulation.

Meyen calls it the "Respirations-ring," and says that it is a respiratory organ. He first described the cilia, but denies the existence of any aperture leading into the organ.

In *S. mucronata,* not perceiving that he has to do with the very same organ under a different form, he describes the "ciliated sac" as a testis. The languet he calls simply "Haken."

Eschricht gives it and the languet together, the name of "das längliche organ," and considers it as a tactile organ analogous to the pulps of bivalves. He rightly describes the nervous cords connecting it with the ganglion.

Sars confirms Eschricht's view, and considers the organ as analogous to the tentacles of the Ascidians, which, however, cannot be the case, as in many Ascidians (e.g. *Clavelina*) the tentacles and the "languets" co-exist*.

M. Milne-Edwards figures the "ciliated fossa" as the "fossette prébranchiale" in the plates of the last (commemorative) edition of Cuvier's 'Règne Animal.'

74. *The Structure of the Heart.*—Eschricht and Sars describe the heart to be composed of a series of vesicles, which is certainly a mistake, arising from the fact that the heart always presents two or three constrictions, so as to appear almost moniliform.

75. *Tubular System.*—This is figured by MM. Quoy and Gaimard (pl. 88, fig. 12) in *Salpa pinnata,* under the name of "vaisseaux mésenteriques." Is it to this structure to which M. Krohn refers, when he says that "the meshes or lamellæ of the elæoblast are traversed by numerous vessels opening into two trunks, which apparently form the attachment between this organ and the visceral nucleus?"

Perhaps also it is to this system that Eschricht refers when he speaks of the intestine as beset with "stalked granules."

76. *The Gemmiferous Tube.*—Cuvier, Savigny, Chamisso and Quoy and Gaimard consider this structure as more or less partaking of the nature of an ovary.

Meyen mistakes it for a liver in *Salpa democratica.* Eschricht describes the process of development of the young from the gemmiferous tube and their connection with it very carefully; but he does not seem to consider it as mere gemmation.

He calls the organ "Keim-röhre," germ-tube, and considers it as a "quite new form" of propagative organ. From the mode of expression in the following paragraph he evidently thinks the propagation here to be in some manner sexual. "Die Eintheilung in Strecken deren jede Fötus von einerlei Ausbildung enthält, deutet allzu bestimmt auf verschiedene Befruchtungen hin, als das hier nicht eine wiederholte Geburt in längeren Zwischenzeiten anzunehmen wäre."

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* In the *Cynthia* examined by the author (see note (65.), the "ciliated sac" was seated upon a tubercle, but there was no "languet."

Sars conjectures that the solitary fœtuses arise by a process of sexual generation, but does not state very clearly what he considers to be the nature of the production of the associated forms.

77. *The Placenta.*—Cuvier speaks of finding a fœtus attached to the parent by a pedicle; and referring to a figure, he says, "Ce corps rond (evidently the placenta) seroit-il un organe servant uniquement pendant le temps de la gestation pour établir l'union entre la mère et son petit et qui s'effaceroit ensuite?"

Chamisso calls the pedicle of attachment "pediculus umbilicalis;" the placenta, "globulus opacus."

Meyen was the first to give this structure the name of placenta, and his account of it is so very clear and precise, that it is wonderful it should have been subsequently forgotten or overlooked. He says, "Wir haben bei ganz jungen Individuen den Verlauf der Blut-bewegung selbst bei 200-maliger Vergrösserung beobachten können. Der Muttertheil der Placenta hat nur wenige Gefässen um so mehr aber der Fötus-theil, in dem sich ein ausserordentliches Convolut von Gefässen befindet, das sich in einem Stämme endigt, der sich in das grosse Bauchgefäss ganz in der Nähe des Hergens ergiesst. Ein unmittelbares uebergehen der Blutgefässe ausdem Muttertheil in dem Fötus-theil haben wir nicht sehen können. Hat der Fötus die hinlängliche Ausbildung im Leibe der Mutter erreicht, so verwächst das grosse Blut-gefäss und die Placenta fällt ab."—P. 400.

78. After what has been stated concerning the development of the two forms of the *Salpæ*, it would be useless to enter upon the consideration of the various theories propounded since the time of Chamisso (such as that of Eschricht for instance) to account for the phenomena they present.

It may be sufficient to say, that it is now quite certain that the *Salpæ* never unite after being once separated, and that they do not produce successive broods of a different form.

Much remains to be done with regard to the minute process of development of the young forms of both kinds, and to this difficult inquiry it is to be hoped that future observers will address themselves*.

In order to avoid the necessity of incessant references to the text, a list of the works consulted and alluded to, is here subjoined in chronological order.

Salpa.—Forskahl. Descriptiones Animalium, 1775.
Browne. Natural History of Jamaica, 1785.

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* An essential service to zoology will be rendered by any one who will revise and critically compare the species of the *Salpæ*. At present, they are in a most unedifying state of hopeless confusion.

Cuvier. Mémoires du Museum, 1804.
Savigny. Mémoires sur les Animaux sans Vertèbres, 1816.
Quoy and Gaimard. Freycinet's Voyage, 1817–20.
Chamisso. De Animalibus quibusdam e classe Vermium Linnæana. Fasc. i. 1819.
Chamisso. Fasciculus secundus, Nova Acta Acad. Nat. Cur. tom. x. 1821.
Kuhl and Von Hasselt. Annales des Sciences Naturelles, t. iii. 1824.
Eschscholtz. Isis, 1824.
Quoy and Gaimard. D'Urville's Voyage, 1826–29.
Meyen. Beiträge zur Zoologie, Nova Acta Nat. Cur. t. xvi. 1832.
Milne-Edwards. Annales des Sciences Naturelles, 1840.
Krohn. Ueber die Mannlichen Zeugungs Organe der Ascidien u. Salpen, Froriep's Notizen, 1841.
Eschricht. Isis, 1843–44.
Sars. Fauna Littoralis Norvegiæ, 1846.
Steenstrup. Ueber das Vorkommen d'Hermaphrodismus, 1846.
Krohn. Annales des Sciences Naturelles, 1846.

The Ascidians in general.—Lister. Philosophical Transactions, 1834.
Milne-Edwards. Sur les Ascidies composées, 1841.
Van Beneden. Mémoires de l'Académie Royale de Bruxelles, t. xx.
Forbes and Goodsir. Edinburgh New Philosophical Journal, 1841.
Rupert Jones. Art. *Tunicata*, Cyclopædia of Anatomy and Physiology.

Pyrosoma.—Peron. Annales du Museum, 1804.
Lesueur. Journal de Physique, 1815.
Savigny. *Op. cit.*
Milne-Edwards. Comptes Rendus, 1840.
Milne-Edwards. Annales des Sciences, t. xiii.

XXV. *Remarks upon* Appendicularia *and* Doliolum, *two genera of the* Tunicata.

By THOMAS HENRY HUXLEY, *Assistant-Surgeon R.N.*
(*late of H.M.S. "Rattlesnake"*). *Communicated by Prof.* EDWARD FORBES, *F.R.S.*

Received February 26,—Read March 27, 1851.

79. THE genus *Appendicularia* was first formed by CHAMISSO from an animal found by him near Behring's Straits, and thus described: "Corpus gelatinosum, subovoideum, vix quartam pollicis partem æquans, punctis rubescentibus (interaneis) transparentibus. Appendix gelatinosa cestoidea, rubro marginata corpore duplo vel triplo longior. Motu flexuoso natationi inserviens. Motus animalis vividus." And he adds, "genus ultra recognoscendum, generi Cestum (LES.) forsitan affine." The specific name "flagellum" was conferred upon the animal, and it was figured (P. XXXI.), though very indifferently*.

Ten years afterwards (in 1828) MERTENS, voyaging in the same regions, rediscovered this animal, and he subsequently published a long account of it† under the name of *Oikopleura Chamissonis.*

The only other notice of the genus (so far as I am aware) is that given by MM. QUOY and GAIMARD‡. It was observed in immense masses off Algoa Bay, South Africa, and was called by them *Fritillaria,* until they afterwards became acquainted with the descriptions of CHAMISSO and MERTENS. Recognising as they do the priority of discovery of the former, they yet adopt the name conferred by the latter, and, without any very just reason, give to the specimens observed by themselves a new specific name, *O. bifurcata.*

Vast numbers of the species observed by myself were found on the coast of New Guinea and in the Southern Pacific. The differences separating this from the species observed by MERTENS are not to my mind sufficient to form the basis of any specific distinction, and as the description given by MM. QUOY and GAIMARD, and by CHAMISSO, are too imperfect to establish any certain distinguishing characters in their case either, I shall consider that only one species has been observed. And as I can see no reason for the construction of a new and by no means euphonious name by MERTENS, I shall retain both the generic and specific names given by CHAMISSO, *Appendicularia flagellum* (CHAMISSO), Syn. *Oikopleura Chamissonis* (MERTENS), *Oikopleura bifurcata* (QUOY and GAIMARD).

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* De Animalibus quibusdam et classe Vermium, Fasc. Secundus. Nova Acta Acad. Cur. tom. x. 1821.

† In the Mémoires de l'Acad. Imp. de St. Pétersbourg, 1831.

‡ Zoology of the Astrolabe, vol. iv. p. 304.

80. The animal has an ovoid or flask like body, Plate XVIII. fig. 1, one-sixth to one-fourth of an inch in length, to which is attached a long curved lanceolate appendage or tail, by whose powerful vibratory motions it is rapidly propelled through the water.

The body frequently appears wrinkled and crumpled externally, and its upper, smaller extremity has rarely clear and well-defined edges. The lower part of the body is frequently separated from the upper by a slight cleft or constriction, fig. 4, and it is here that Mertens places the orifice of the mouth, supposing indeed that the upper part of the body plays the part of a maxilla!

81. The smaller extremity of the animal is perforated by a wide aperture (*d*) which leads into a chamber, which occupies the greater part of the body, and at the bottom of this chamber is the mouth. The chamber answers to the respiratory cavity of the *Tunicata*, and is lined by an inner tunic distinct from the outer; the space between these, as in the *Salpæ*, being occupied by the sinus system.

On the side to which the caudal appendage is attached, an endostyle (*c*), altogether similar to that of the *Salpæ*, lies between the inner and outer tunics; and opposite to this, or on the ventral side, close to the respiratory aperture, there is a nervous ganglion, to which is attached a very distinct spherical auditory sac, containing a single, also spherical, otolithe. The sac is about $\frac{1}{200}$th of an inch in diameter. The otolithe about $\frac{1}{800}$th, figs. 1, 2, 4 *a*.

Anteriorly, a nerve is given off from the ganglion (*a*) which becomes lost about the parietes of the respiratory aperture; another large trunk passes backwards (*b*) over the left side of the œsophagus, and between the lobes of the stomach, until it reaches the appendage, along the axis of which it runs, giving off filaments in its course, fig. 2. I did not observe anything resembling the "languet" of the *Salpæ*; but Mertens describes two leaf-like laminæ existing, one on each side of a "semicylindrical" body, which seems to be the nervous ganglion.

82. There is no proper branchia; but that organ seems to be represented by a richly ciliated band or fold (*e*) of the inner tunic, which extends from the opening of the mouth forwards, along the ventral surface of the respiratory cavity, to nearly as far as the ganglion; when it divides into two branches, one of which passes up on each side, so as to encircle the cavity (*f*). This circlet evidently represents the "ciliated band" of *Salpa*.

The mouth (*g*) is wide, and situated at the posterior part of the ventral paries of the respiratory chamber. The œsophagus (*h*) short, and slightly curved, opens into a wide stomach (*i*) curved transversely, so as to present two lobes posteriorly.

Between the two lobes, posteriorly, the intestine (*k*) commences, and passing upwards (or forwards) terminates on the dorsal surface just in front of the insertion of the caudal appendage (*l*).

The heart lies behind, between the lobes of the stomach. I saw no corpuscles, and the incessant jerking motion of the attached end of the caudal appendage rendered it very difficult to make quite sure even of the heart's existence.

83. MERTENS describes a vascular system, consisting of an aortic vessel, which runs forwards on the dorsal surface, and of a principal vein of a red colour, which passes to the ventral surface, and there divides into three branches, one of which runs forwards to the "semicylindrical body" (ganglion?), and the other two pass to the dorsal region.

A circular canal communicating with the aortic vessel exists, he says, on each side of the anus, and is connected with the ventral vessel by means of a vessel, through which no corpuscles were seen to pass.

I have seen nothing of this vascular system. The caudal appendage (A) is attached or rather inserted into the body on the dorsal surface just behind the anus. It consists of a long, apparently structureless, transparent, central axis (*m*), rounded at the attached, and pointed at the free end. This axis is enveloped in a layer (*o*) of longitudinal, striped, muscular fibres; which form the chief substance, in addition to a layer of polygonal epithelium cells, of the broad alary expansion on each side of the axis.

I did not observe the lateral canal containing air, described by MERTENS.

84. The only unequivocal generative organ I found in *Appendicularia* was a testis (*p*), consisting of a mass of cells developed behind and below the stomach, enlarging so much in full-grown specimens as to press this completely out of place.

In young specimens the testis is greenish, and contains nothing but small pale circular cells; but in adults it assumes a deep orange red-colour, caused by presence of multitudes of spermatozoa, whose development from the circular cells may be readily traced.

This orange-red mass, or rather masses, for there are two in juxtaposition, is described by MERTENS as the "Samen-behälter" or vesiculæ seminales. He describes them as making their exit, bodily, from the animal, and then becoming diffused in the surrounding water. This circumstance, indeed, appears to have furnished his principal reason for believing these bodies to be what the name indicates.

The spermatozoa have elongated and pointed heads about $\frac{1}{5000}$th of an inch in length, and excessively long and delicate filiform tails.

MERTENS describes as an ovary, two granulous masses, which he says lie close to the vesiculæ seminales, and have two ducts, which unite and open into this "ovisac."

This appears to me to be nothing more than the granulous greenish mass of cells and undeveloped spermatozoa, which exists in the testis at the same time as the orange-red mass of fully developed spermatozoa.

I saw nothing of any ducts, nor do I know what the "ovisac" can be, unless it be a further development of an organ which I found in two specimens (fig. 3 *q*), consisting of two oval finely granulous masses, about $\frac{1}{300}$th of an inch in diameter, attached, one on each side of the middle line, to the dorsal parietes of the respiratory cavity, and projecting freely into it.

MERTENS' "ovisac" has about the same position as these bodies, and he says he saw "living animals" proceed from it, the part being afterwards evidently collapsed.

Unfortunately, however, he does not appear to have noticed the endostyle, whence confusion might readily arise; nor does he give the slightest hint as to the nature of the "living animals" which he saw come forth.

85. Still less am I able to give any explanation of the extraordinary envelope or "House" to which, according to Mertens, each *Appendicularia* is attached in its normal condition. I have seen many hundred specimens of this animal, and have never observed any trace of this structure; and I have had them in vessels for some hours, but this organ has never been developed, although Mertens assures us that it is frequently re-formed, after being lost, in half an hour.

At the same time it is quite impossible to imagine, that an account so elaborate and detailed, can be otherwise than fundamentally true, and therefore, as Mertens' paper is not very accessible, I will add his account of the matter, trusting that further researches may clear up the point.

The formation of the envelope or "Haus" commences by the development of a lamina from the "semicylindrical organ" (ganglion?). This, as it grows, protrudes through the opening at the apex of the animal (respiratory aperture). Its corners then become bent backwards and inwards, and thus a sort of horn is formed on each side, the small end of which is turned towards the apex of the animal, while its mouth looks backwards, downwards and outwards.

At the same time two other horns are developed upwards (the animal is supposed to have its small end downwards), one on each side. These are smaller and more convoluted than the others.

This four-horned structure consists of a very regular network of vessels, in which, at the time of the development of the organ, a very evident circulation is visible; the blood-corpuscles streaming from the attached end of the organ. "The clearness with which the circulation was perceptible, together with the great abundance of vessels and the large extent over which they were spread, were circumstances which led me (says Mertens) to believe this truly enigmatical structure to be an organ, whose function was the decarbonization of the blood. The ease with which the animal becomes separated from this organ is no objection to this view; the necessity there seems to exist for the reproduction of the latter rather confirming my opinion."

It is highly desirable that more information should be gained about this extraordinary respiratory organ, which, if it exist, will not only be quite *sui generis* in its class, but in all animated nature. And in a physiological point of view, the development of a vascular network, many times larger than the animal from which it proceeds, in the course of half an hour, will be a fact equally unique and startling.

86. As to the zoological relations of *Appendicularia*, its discoverer, as we have seen, considers that "it may possibly be allied to *Cestum*," a conjecture in which no one can possibly coincide.

Mertens, on the other hand, says, "The relation of this animal with the *Pteropoda* is unmistakeable; if the *Oikopleura* possessed two tail-like appendages, every one would recognize in them the wings of the *Pteropoda*;" and he proceeds to draw, what seems to me, a very forced comparison between *Oikopleura* and *Clio*.

I do not think that any one who has read the preceding pages will be at all disposed to agree with Mertens either.

87. For my own part, I think there can be no doubt that the animal is one of the *Tunicata*. The whole organization of the creature, its wide respiratory sac, its nervous system, its endostyle, all lead to this view.

In two circumstances, however, it differs widely from all *Tunicata* hitherto known. The first of them is, that there is only one aperture, the respiratory, the anus opening on the dorsum; and secondly, that there is a long caudal appendage.

As to the first difference, it may be observed, that, in the genus *Pelonaia*, an undoubted Ascidian, there are indeed two apertures, but there is no separation into respiratory and cloacal chambers. Suppose that in *Pelonaia* the cloacal aperture ceased to exist, and that the rectum, instead of bending down to the ventral side of the animal, continued in its first direction and opened externally, we should have such an arrangement as exists in *Appendicularia*.

With regard to the second difference, I would remark, that it is just the existence of this caudal appendage which makes this form so exceedingly interesting.

It has been long known that all the Ascidians commence their existence as larvæ, swimming freely by the aid of a long caudate appendage; and as in all great natural groups some forms are found which typify, in their adult condition, the larval state of the higher forms of the group, so does *Appendicularia* typify, in its adult form, the larval state of the Ascidians.

Appendicularia, then, may be considered to be the lowest form of the *Tunicata*; connected, on the one hand, with the *Salpæ*, and on the other with *Pelonaia*, it forms another member of the hypothetical group so remarkably and prophetically indicated by Mr. MacLeay, and serves to complete the circle of the *Tunicata*.

88. *Doliolum*.—This name was given by Otto* to a free-swimming gelatinous case, altogether structureless, of which a single example was found by him in the Gulf of Naples. Its nature is altogether unknown, for it is hardly justifiable, in the face of Otto's words, "Die Ränder sind aber völlig glatt ohne alle Spur von Zerreissung, nirgend sieht man inwendig Rauhigkeiten wo die Eingeweide angessessen haben könnten und die äussere Haut geht ohne Unterbrechung in die innere über," to assume with MM. Quoy and Gaimard, that it is only a *Biphore* whose intestines have been destroyed by a parasitic *Phronima*.

Furthermore, Otto states that the animal moved by a "worm-like contraction of its walls," which by no means describes the mode of contraction of the *Salpæ*, with which animals he was perfectly acquainted, and with a mutilated specimen of which, he expressly states he might, except for its peculiar motion, have confounded the form he describes*.

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* Nova Acta Acad. Curiosorum, t. xi. pars secunda, pp. 313 and 314.

MM. Quoy and Gaimard†, altogether denying the existence of Otto's genus as a distinct form, appropriated his name for two species of tunicate animals observed by them at Amboyna and Vanikoro, and which they justly recognized as being very closely allied to the *Salpæ*.

Of these two species, *Doliolum denticulatum* and *Doliolum caudatum*‡, the former is the only one with which I have met.

MM. Quoy and Gaimard give only the following short description:—

"Its form is nearly that of the vessel from which we have derived its generic name, that is to say, it is enlarged in the middle and narrowed at its two extremities where the openings are situated. The anterior opening is somewhat projecting and denticulated like a crown. Eight circles in relief surround the body at nearly equal distances. They have rather a polygonal than a circular form, and are probably vessels. In the interior the branchia is visible, divided into two portions, which have their oblique lamellæ upon a central vessel, as in the Pectinibranchiata. Near the union of the two divisions posteriorly is the heart, and between them (?) a vessel, the aorta, ascends; not far from the heart is a transparent nucleus. This is all that the vivacity of the mollusk, which bounded like an arrow through the water, allowed us to make out of its organization."

Although I cannot think that MM. Quoy and Gaimard have done well in appropriating Otto's name to an animal confessedly different from that which he describes, it will perhaps cause least confusion to follow their example.

The specimens which I examined were taken in the South Pacific, a little to the northward of Sydney, N.S.W., between Sydney and New Zealand, and in considerable numbers just at the entrance of the Bay of Islands.

89. *Doliolum denticulatum*, figs. 5, 6.—A small transparent body, varying in length from one-sixth to one-third of an inch, and looking very much like a barrel open at each end, which swims by contracting its whole body, and forcing the water out at one or the other extremity.

The apertures are considerably less in diameter than the central cavity. The anterior (*d*) is produced into a sort of tube, with about twelve rounded dentations, which are turned inwards. The base of the tube is surrounded by a thickened muscular rim.

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* Prof. E. Forbes informs me that a body answering precisely to Otto's description, was found by him, occurring in considerable numbers, on the coast of Scotland, and was eventually discovered to be nothing more than the detached siphonic tubes of *Solenocurtis strigillatus*.

† Voyage de l'Astrolabe. Zoologie, t. iii. part. 2. p. 599.

‡ Little more than a description of the outward form is given by MM. Quoy and Gaimard of the *Doliolum caudatum*, but it strikingly agrees in everything with what one of the associated forms of the singular genus *Anchinaia* might be supposed to become if set free; unfortunately, the description of the latter genus itself is very scanty. See note (60.)

Has the *Doliolum denticulatum* itself been ever an attached form? From certain appearances (90.) this appears very possible.

The posterior extremity is similarly produced into a short tube with a thickened base, but the tube looks outwards, and its walls are very delicate, and consist of fine fibres like those of the fin of *Sagitta*.

90. The body of the animal consists of two tunics, an inner and an outer*, which surround a wide central respiratory cavity.

Six muscular bands (*t*), pretty nearly equidistant, gird the inner tunic.

In some specimens a sort of shrivelled tubular process projects on the dorsal surface posteriorly between the two last muscular bands. Is this the remains of an earlier pedicle of attachment?

91. A tubular endostyle (*c*) lies in the dorsal sinus between the first and third muscular bands.

In the ventral sinus a round ganglion (*a*) lies just in front of the third muscular band. It gives off several long nerves, four of which are especially remarkable, and run diagonally to the anterior and posterior apertures. There is no auditory sac nor otolithes.

92. The branchiæ divide the respiratory cavity into an anterior and a posterior chamber. They are formed by the epipharyngeal and hypopharyngeal (*x*) bands which stretch aross the respiratory cavity, supporting on each side a number of tubular bars (*y*). In the upper and lower division of the branchiæ, these bars are adherent to the walls of the respiratory cavity, *i. e.* to the inner tunic, and there their canals open into the lateral sinuses; but in the middle part of the branchiæ their extremities unite and form loops without adhering to the inner tunic, merely lying against it. There is a free passage for the water between the bars, and on each side of the central supporting bands.

The edges of the bars are richly ciliated, and the cilia of their opposite sides move in opposite directions.

Although it appeared quite certain that the canals of the bars communicated with the sinus system, yet no blood-corpuscles could be traced into them.

The branchial bars did not extend so far forward above as below. In the former case they reach as far as the second muscular band only, in the latter, beyond the first; seen from above or below, the branchia appeared as an oval plate, with a clear space down its middle and transverse bars on each side.

93. The mouth (*g*) opens in the middle of the upper division of the gill, just anterior to the fourth muscular band; a narrow œsophagus (*h*) leads from it into a two-lobed stomach (*i*); from this a narrow intestine passes, and bending a little upwards and then downwards and to the left side, terminates in a papillary (*l*) anus. Just at its bend

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* The outer tunic, which I consider as homologous with the test and outer tunic of the Ascidian fused together, was found by MM. Löwig and Kölliker to contain cellulose, whence they concluded the Ascidian nature of the animal, a deduction strikingly confirmed by anatomical investigation.

the intestine gives attachment to three or four small cæca (*s*), which appear to represent a liver, and a system of transparent anastomosing tubules, similar to that described in *Salpa*, arises from the stomach and envelopes the intestine in a network.

The heart (*r*) lies above and in front of the mouth. In structure it resembles that of *Salpa*. There are no vessels of any kind, the blood-corpuscles making their way at random among the viscera. No reversal of the circulation was observed in this Ascidian.

94. All the specimens examined possessed only the male generative apparatus, in the shape of a long tubular* testis (*p*), placed on the right side and below, and opening posteriorly into the respiratory chamber by a papillary elevation (*p'*) just before the penultimate muscular band.

The testis lies quite freely in the sinus, and is bathed by the blood (fig. 7).

When most fully developed the testis nearly equals the body in length; but in young specimens it may be not more than one-half to one-third that size.

The young testis is a delicate sac, containing a mass of circular cells, about $\frac{1}{3300}$th of an inch in diameter, of a pale greenish colour, and flattened.

As development proceeds, these cells assume a redder tint, and become perfect spermatozoa, with elongated cylindrical heads $\frac{1}{2500}$th of an inch in length, and very delicate, long filiform tails.

95. There is a small cavity (*u*) resembling the ciliated fossa of the *Salpæ*, seated upon the anterior face of the singular process of the ventral paries of the respiratory cavity.

This process lies anterior to the first muscular band; it is somewhat conical and excavated behind. The two lips of the excavation are thickened and ciliated, and the right lip is continuous on the left side with a ciliated band, which runs up parallel with the first muscular band, passes over to the right side, and running down, becomes eventually lost in the right portion of the base of the conical process.

This would seem to be a rudimentary languet. A number of small granular masses were always to be seen attached to the inner tunic close to the posterior aperture.

The structure of the branchiæ of this Ascidian, the position of the two orifices, and the structure of the testis, all indicate a position for *Doliolum* intermediate between *Salpa* and *Pyrosoma*.

Its apparent unisexuality very likely arises from the ova being developed, and leaving the parent in a younger state than any I examined. I have elsewhere mentioned the liability to deception in *Salpa* from a similar cause.

Note.—Since writing the above I have found a short notice of *Appendicularia* in MÜLLER's Archiv for 1846†, under the name of *Vexillaria flabellum*. The de-

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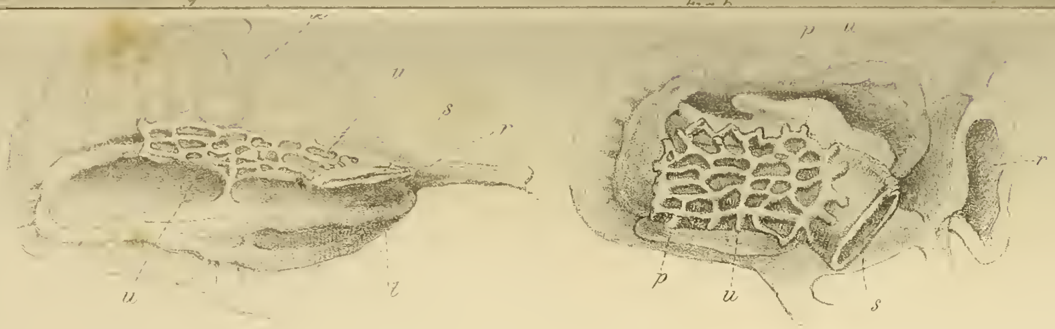
* Very similar to that of *Salpa cristata*, described as an hepatic organ by MEYEN.

† Bericht über einige neue Thierformen der Nordsee.



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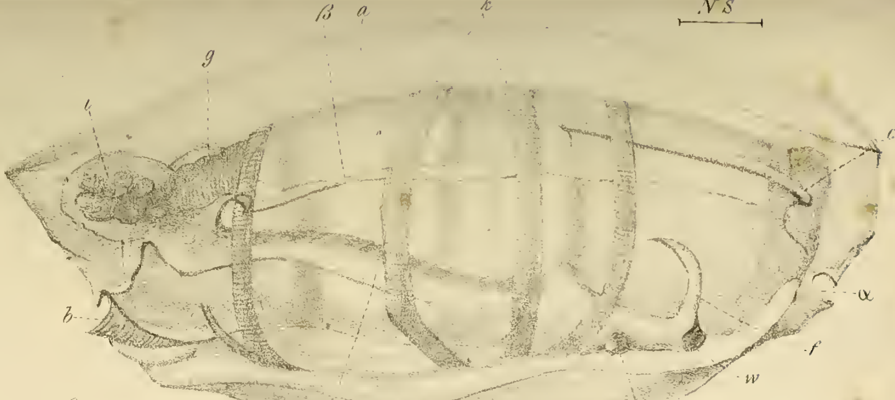

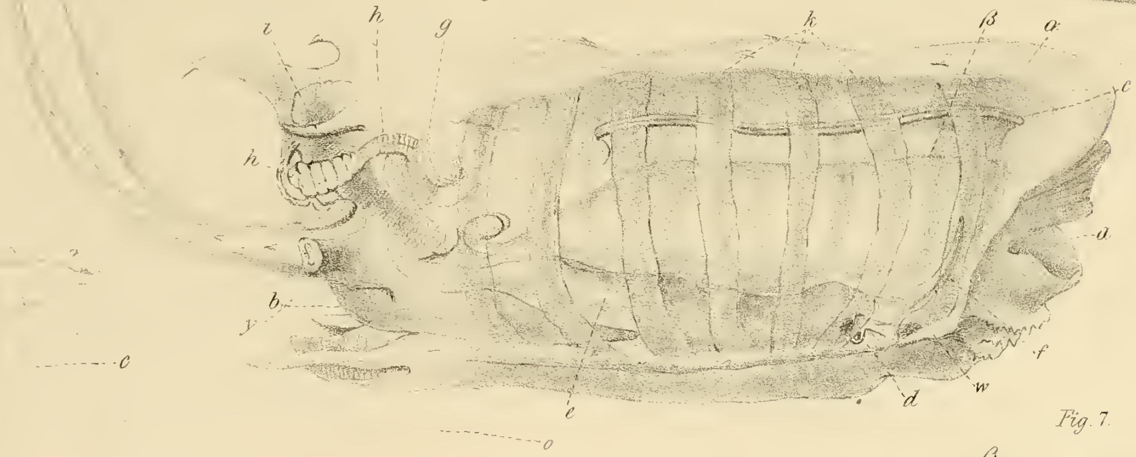

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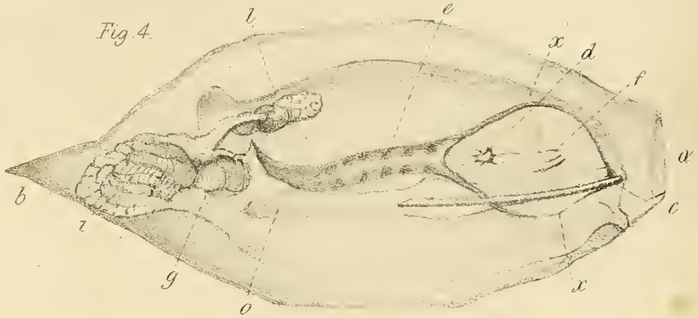

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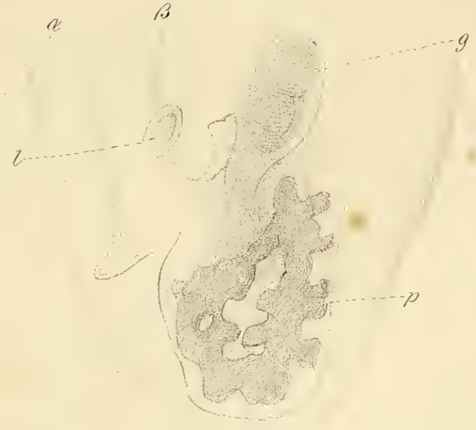

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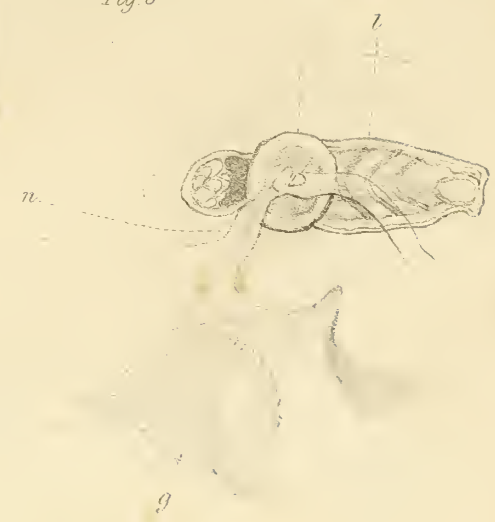

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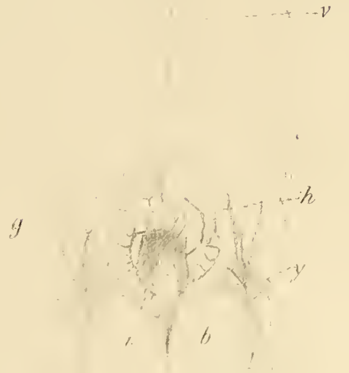

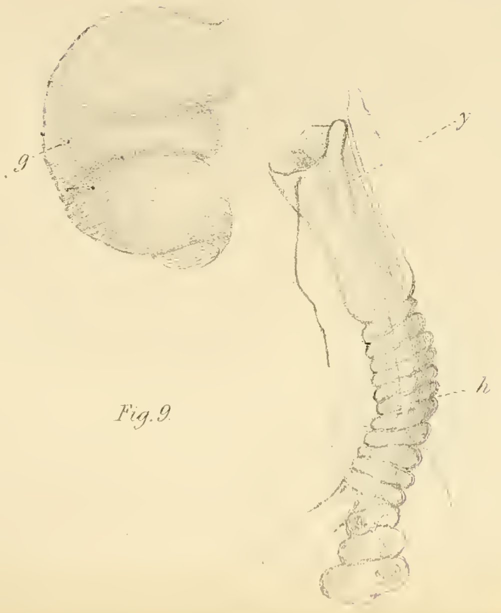

Fig. 9.

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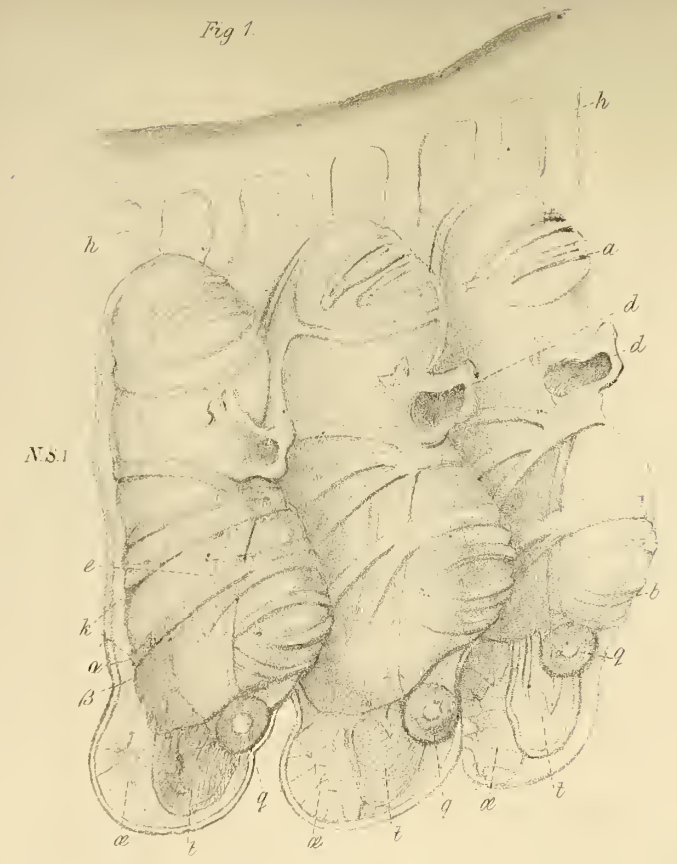

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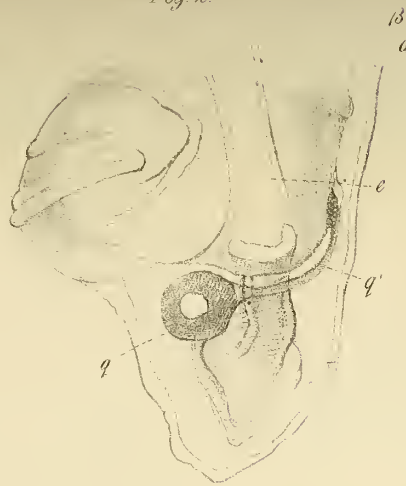

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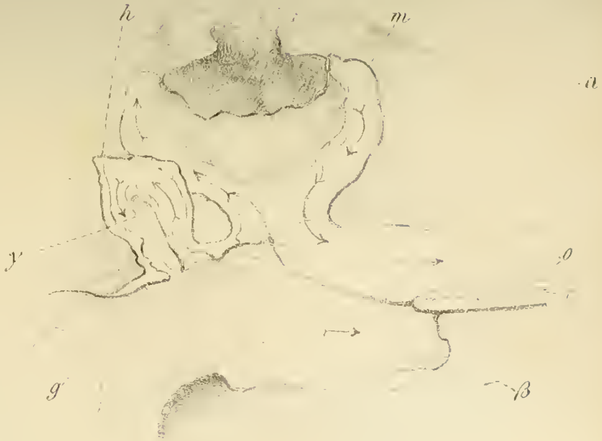

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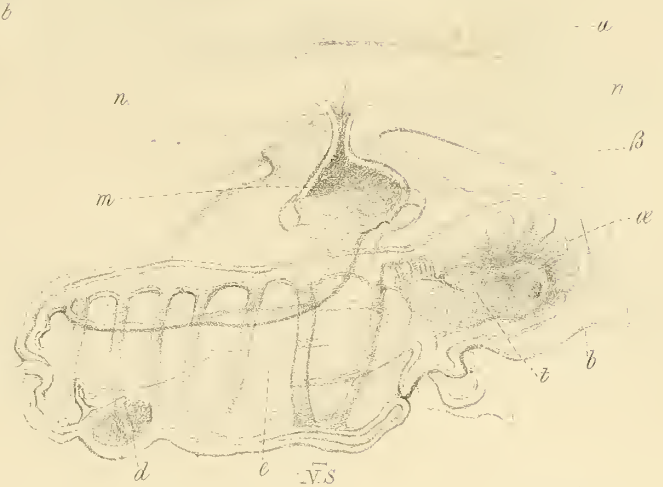

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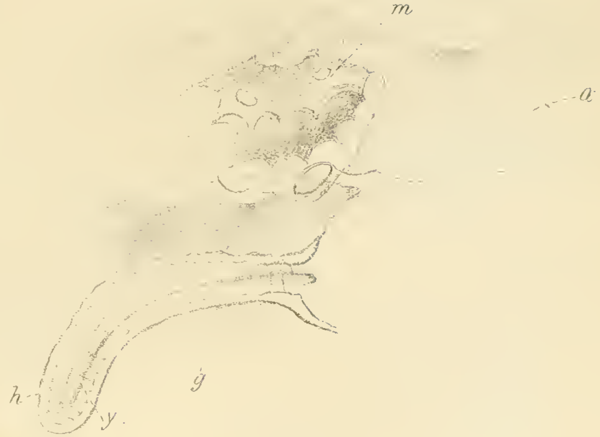

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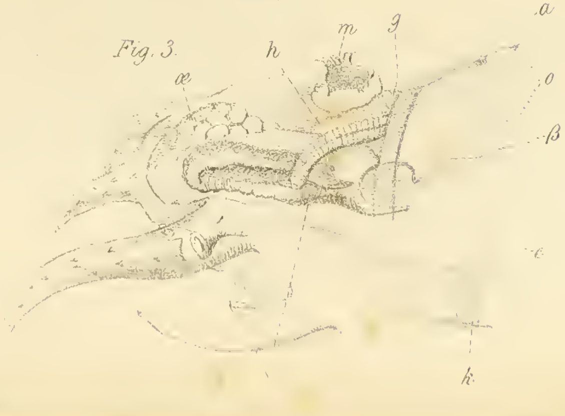

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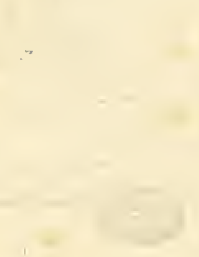

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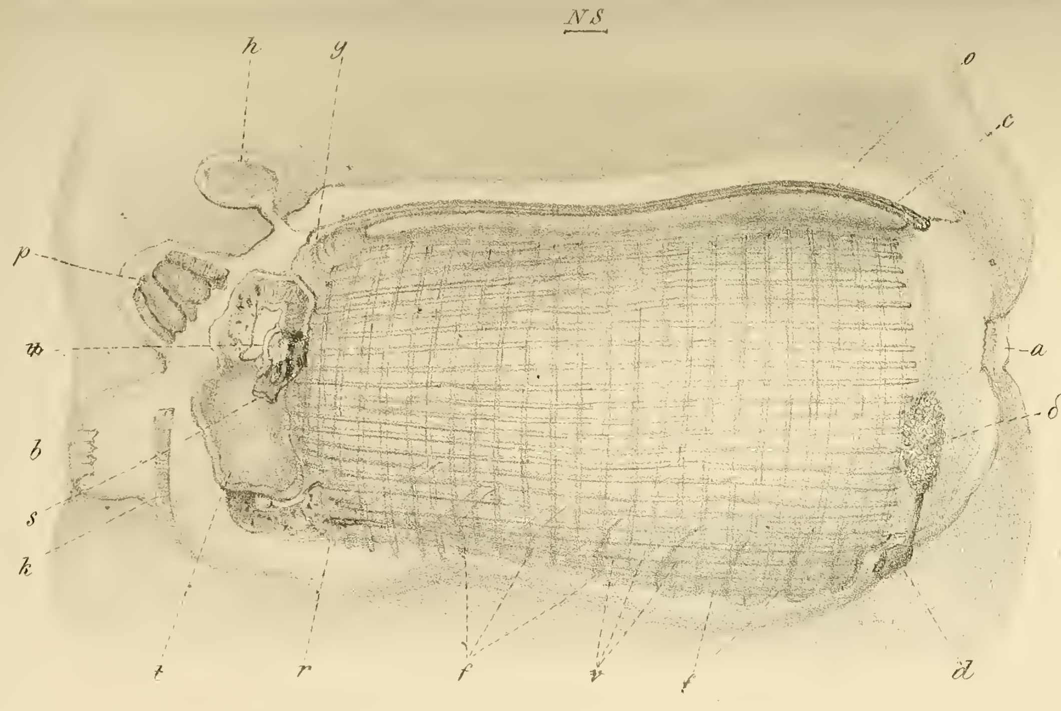

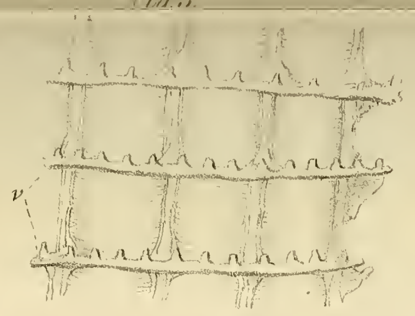

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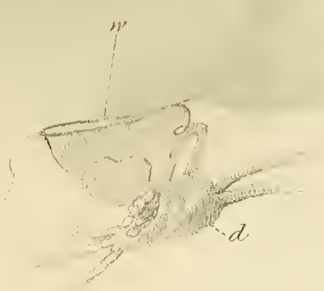

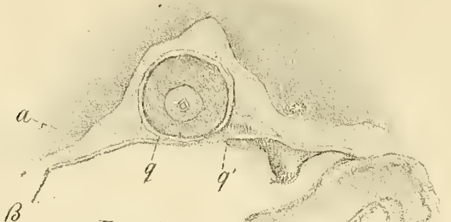

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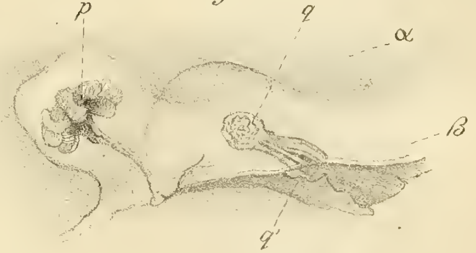

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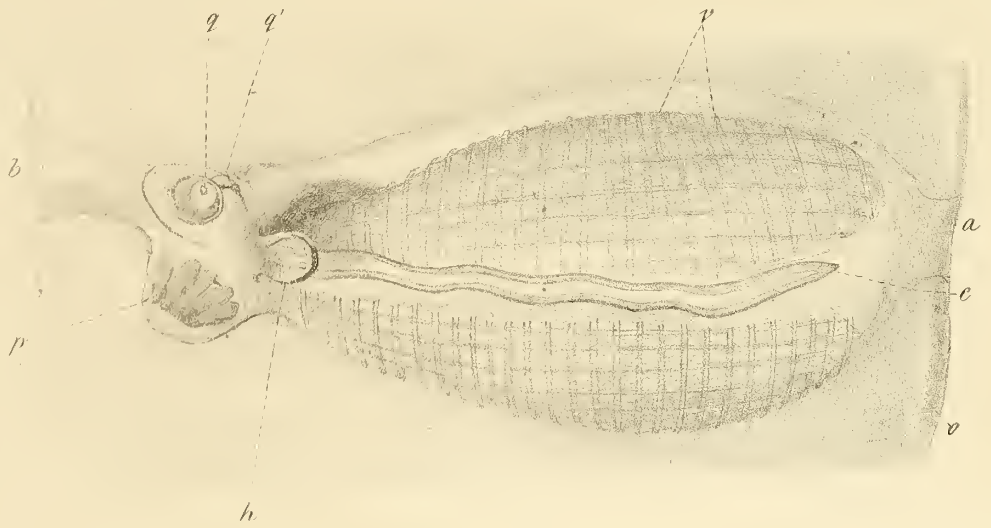

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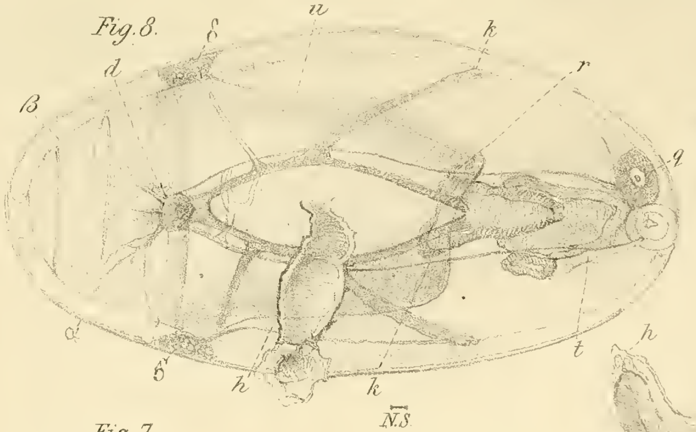

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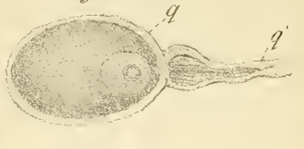

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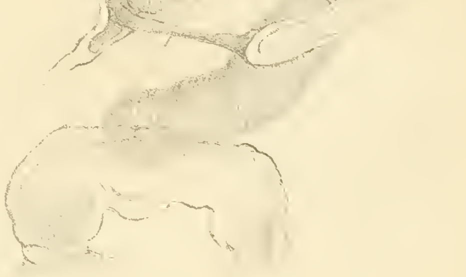

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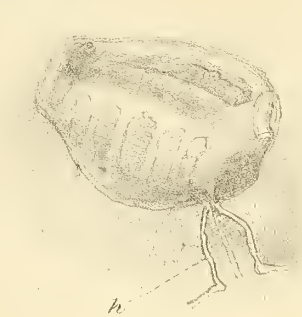

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scriber, Prof. Müller, confesses that he does not know in what division of the animal kingdom to place this creature; and his account of its structure is not a little vague, including little more than its mere external appearance. He does not seem to have observed anything corresponding to the "Haus" of Otto.

Description of the Plates.

PLATE XV. *Salpa.*

Fig. 1. *Salpa* A.
Fig. 2. *Salpa* B.
Fig. 3. Dorsal view of *Salpa* A, the muscular bands being omitted.
Fig. 4. Dorsal view of *Salpa* B, the muscular bands being omitted.
Fig. 5. Intestinal canal of *Salpa* A.
Fig. 6. Intestinal canal of *Salpa* B.
Fig. 7. Dorsal view of extremity of *Salpa* B.
Fig. 8. Part of the respiratory chamber of *Salpa* B, showing the fœtus suspended. View from above.
Fig. 9. Connection of the gemmiferous tube with the heart.

PLATE XVI. *Salpa.*

Fig. 1. Young gemmæ (*Salpa* B) attached to the gemmiferous tube.
Fig. 2. Nuclear end of one of these, showing the ovum and its pedicle or gubernaculum.
Fig. 3. Nuclear end of a very young *Salpa* A, just detached.
Fig. 3^a. Placenta and gemmiferous tube of this enlarged.
Fig. 4. Heart, placenta and gemmiferous tube of a young *Salpa* A, showing the rudimentary condition of the last structure.
Fig. 5. Ganglion, otolithic sac and languet.
Fig. 6. Young *Salpa* A, still attached by its placenta in the interior of *Salpa* B.

PLATE XVII. *Pyrosoma.*

Fig. 1. A single "zoöid," viewed from the right side.
Fig. 2. A single "zoöid," viewed from above.
Fig. 3. Part of the branchial network.
Fig. 4. The ovum with its pedicle *in situ.*
Fig. 5. Testis and ovisac *in situ,* both emptied of their contents.

Fig. 6. Ovum and pedicle.
Fig. 7. A young zoöid developed by gemmation.
Fig. 8. A young zoöid separated and enlarged. Viewed from the ventral side.
Fig. 9. Youngest form of gemma observed.
Fig. 10. "Ciliated fossa," with the ganglion and otolithes.

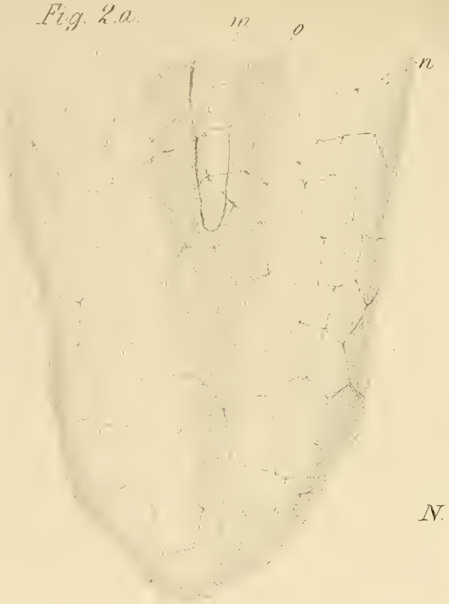
a. Anterior extremity.
b. Posterior extremity.
c. Endostyle.
d. Ganglion and otolithes.
e. Gill band.
f. Languet.
g. Heart.
h. Gemmiferous tube (single gemma in *Pyrosoma*).
i. Nucleus.
k. Muscular bands.
l. Solitary fœtus, or young *Salpa* A.
m. Placenta.
n. Sinus running specially to the placenta.
o. Dorsal sinus.
p. Testis.
q. Ovary, or rather ovum.
q'. Pedicle.
r. Buccal orifice.
s. Anal orifice.
t. Lobe of the stomach.
u. Tubular system.
v. Branchial bars.
w. "Ciliated sac."
x. "Ciliated band."
æ. Eleoblast.
α. External tunic.
β. Internal tunic.
γ. Partition of gemmiferous tube.
δ. Cell masses in *Pyrosoma*.

PLATE XVIII.

Fig. 1. *Appendicularia flagellum.* Much magnified.
Fig. 2. Still more magnified.
Fig. 2^a. Extremity of the caudal appendage.
Fig. 3. Body of *Appendicularia* from behind.
Fig. 4. Individual in which the testis is much enlarged.
Fig. 5. *Doliolum denticulatum,* from the right side.
Fig. 6. *Doliolum denticulatum,* from below.
Fig. 7. A portion of the right wall to show the testis *in situ.*
Fig. 8. The "ciliated sac" and the origin of the "ciliated bands" in *Doliolum.*
Fig. 9. The intestine and heart, with the commencement of the branchiæ.

The letters have throughout the same signification.

a. Ganglion with the auditory vesicle.
b. Nerve.
c. Endostyle.
d. Respiratory or anterior aperture.
e, f. Ciliated bands.
g. Mouth.
h. Œsophagus.
i. Stomach.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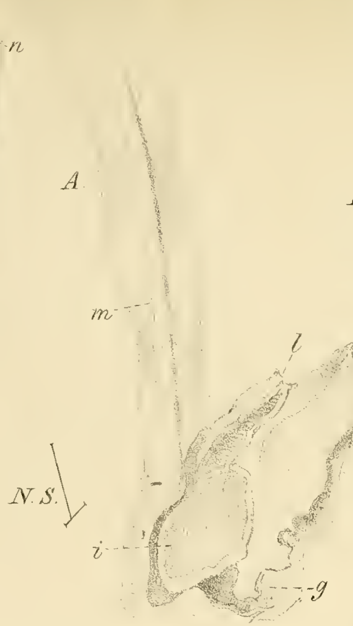
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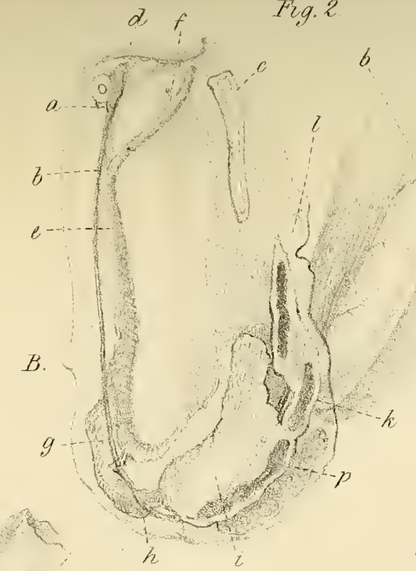
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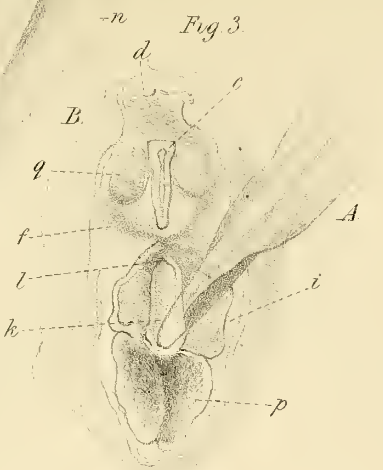
Fig. 3.

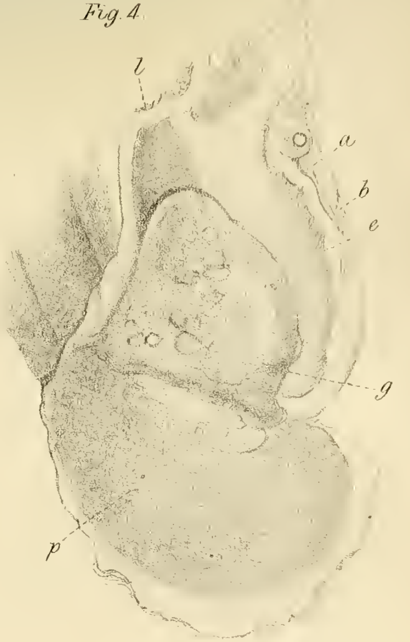
Fig. 4.

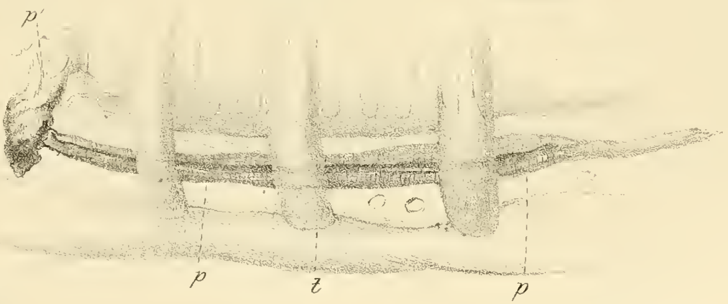
Fig. 7.

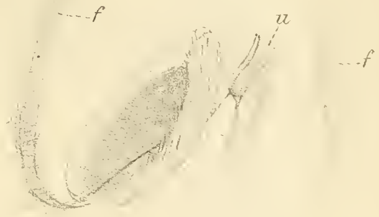
Fig. 8.

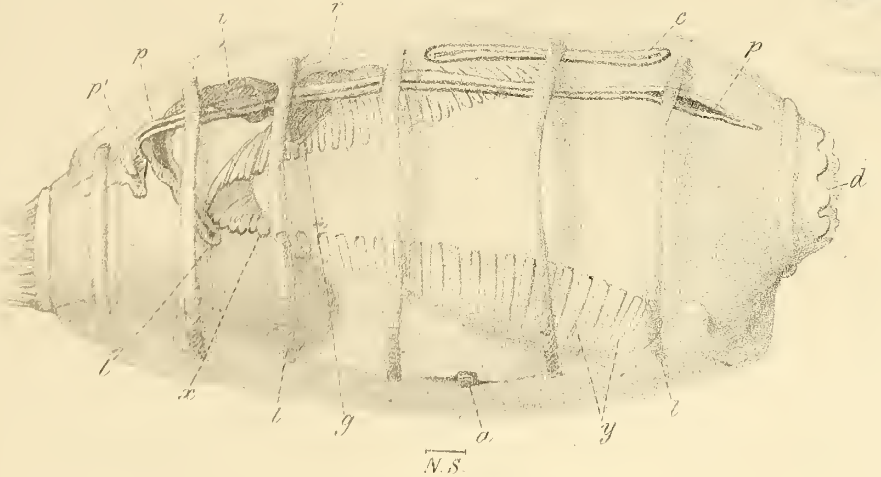
Fig. 5.

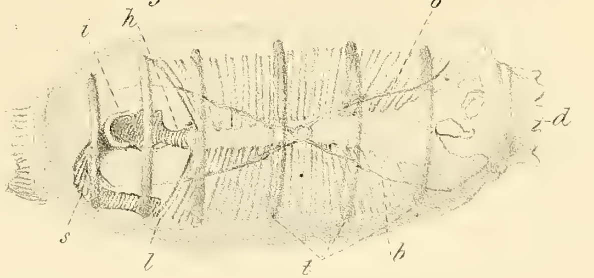
Fig. 6.

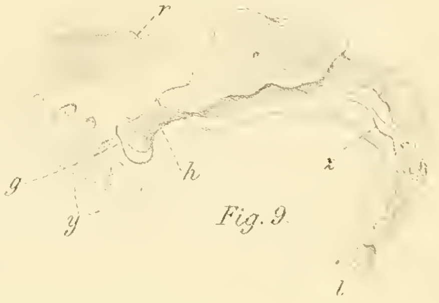
Fig. 9.

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J. Basire, Lith.

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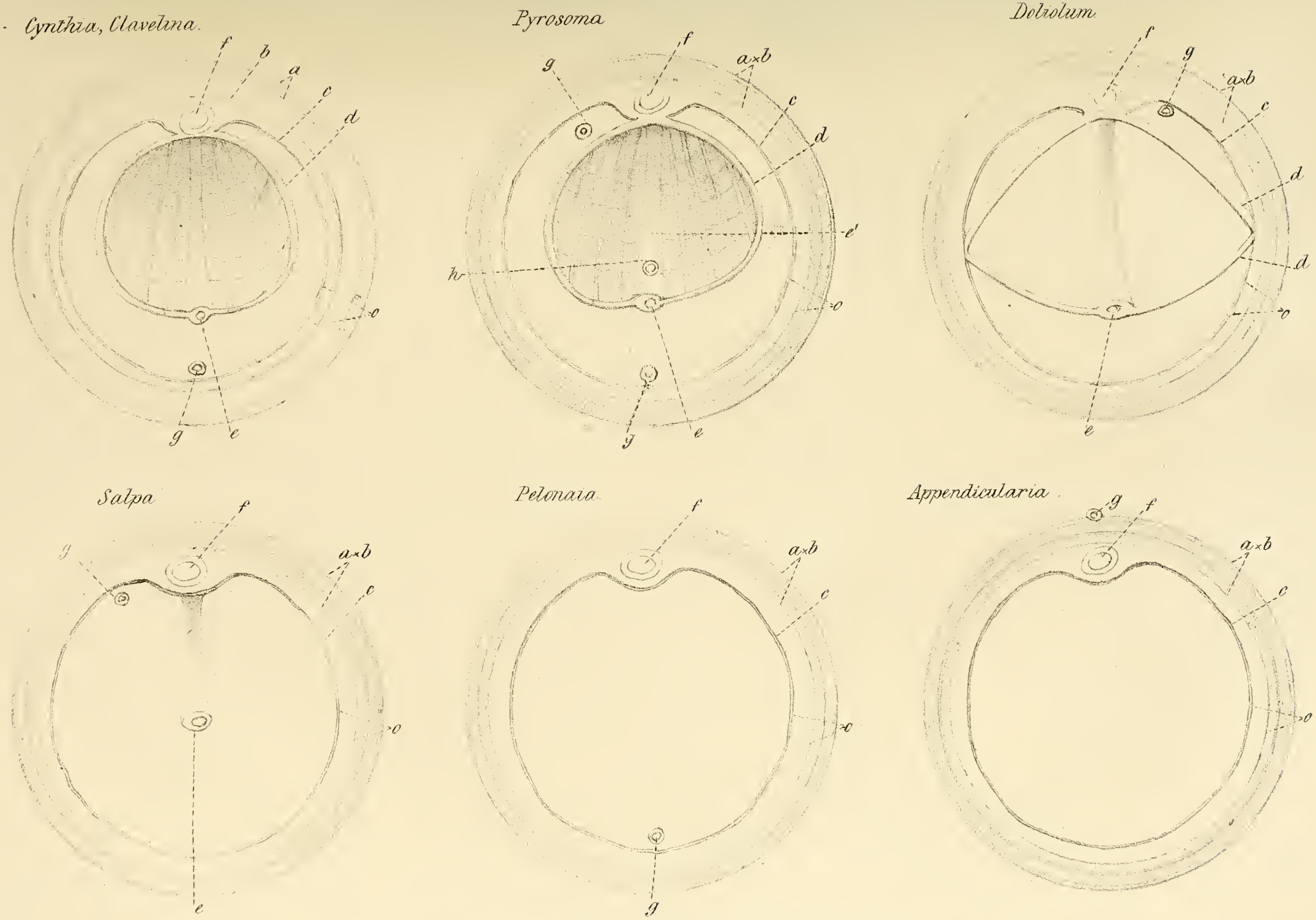

Cynthia, Clavelina. Pyrosoma Doliolum

Salpa Pelonaia Appendicularia

a. Test. b. outer tunic. c. inner tunic. d. branchial sac.
e'. epipharyngeal band. e. hypopharyngial band & Thoracic vessel. f. alimentary canal. g. Anus. h. mouth. o. sinus system.

Sectional Diagrams of Tunicata.

The section supposed to be made perpendicularly to the axis of the branchial cavity.

k. Intestine.
l. Anus.
m. Axis of the caudal appendage.
n. A long membrane of appendage.
o. Bundles of striated muscular fibrils.
p. Testis.
p'. Efferent duct of testis.
q. Supposed ovary.
r. Heart.
s. Liver.
t. Muscular bands.
u. Ciliated sac.
B. The body of *Appendicularia*.
A. The caudal appendage.
x. Hypopharyngeal band.
y. Branchial bars.
z. The system of tubules embracing the intestine.

PLATE XIX.

The diagrams represent imaginary sections of the principal types of the Ascidian family. Without pretending to be strictly accurate, they are sufficiently so to give a just idea of the gradations in structure among the different genera, and of the essential unity of structure which runs through the group.

XXVI. *Researches into the Structure of the Spinal Chord*[*].

By J. Lockhart Clarke, *Esq. Communicated by* Samuel Solly, *Esq., F.R.S.*

Received October 15,—Read December 5, 1850.

By reflecting on certain facts connected with the respiratory movements, and which seem to derive no explanation from our actual knowledge of the structure of the spinal chord, I was induced to undertake a series of observations with the view of determining, if possible, the relations which appear to subsist between the spinal nerves and the respiratory nervous centres. These observations, however, led me into a more extended inquiry than I at first contemplated, the results of which I now venture to lay before the Royal Society.

It is needless to point out the difficulties which attend, not only the minute investigation, but a clear and connected description, of a structure so intricate and delicate as that of the spinal chord. It may be proper however to state, with regard to the contents of this paper, that those facts only which were verified by cautious and repeated examination have been brought forward with confidence; while in cases where the results of my observations were less satisfactory, I have expressed myself with corresponding reserve. Yet, no labour has been spared in order to arrive at correct conclusions. My observations were made, by means of one of Mr. Ross's finest microscopes, on many thousand preparations of the spinal chord of Man, of the Calf, Sheep, Pig, Dog, Cat, Rabbit, Guinea Pig and Frog, and occupied a period of more than two years.

In making these preparations, the two following methods were adopted:—a perfectly fresh chord was hardened in spirits of wine, so that extremely thin sections, in various directions, could be made by means of a very sharp knife. A section so made was placed on a glass slide and treated with a mixture composed of one part of acetic acid and three of spirits of wine, which not only makes the nerves and fibrous portion more distinct and conspicuous, but renders also the grey substance much more transparent. The section was then covered with thin glass, and viewed, first by reflected light with low magnifying powers, and then by transmitted light with higher ones.

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[*] At the time these inquiries were begun, and nearly up to the period of their completion, I had not seen any of the works of Dr. Stilling, and knew no more of his investigations into the structure of the spinal chord than what I had gathered from the anatomical and physiological works published in this country. However nearly, therefore, a few of the facts brought forward in this paper may correspond to the results of his inquiries, I may state that they were made out without any knowledge of Dr. Stilling's views, excepting only those which regard the origin of the spinal nerves. On showing some of my preparations to Mr. Solly and Mr. Grainger, I was advised by those gentlemen to look over the works of Dr. Stilling; and having done so, I shall refer to them whenever they appear to oppose, or coincide with, my own observations.

According to the second method, the section is first macerated for an hour or two in the mixture of acetic acid and spirit. It is then removed into pure spirit, and allowed to remain there for about the same space of time. From the spirit it is transferred to oil of turpentine, which expels the spirit in the form of opake globules, and shortly (sometimes immediately) renders the section perfectly transparent. The preparation is then put up in Canada balsam and covered with thin glass. By this means the nerve-fibrils and vesicles become so beautifully distinct that they may be clearly seen with the highest powers of the micoscope. If the section be removed from the turpentine when it is only semi-transparent, we sometimes obtain a good view of the arrangement of the blood-vessels*.

All the observations described in this paper were made and verified also on sections in a perfectly fresh state and unaffected by any chemical re-agent; and whenever it was proposed to examine the natural structure of any particular part, as the nerves and vesicles, a specimen was selected from an animal immediately after death.

The drawings have been executed by myself with the greatest care, and may be relied on as faithful and exact delineations of what was seen under the microscope. The outlines of all were taken by means of a camera lucida, in order to ensure correctness.

Of the Grey Substance of the Spinal Chord.

At the lower end of the spinal chord the posterior grey substance consists only of a single mass, having a broad and rounded extremity, and formed, as we shall presently see, by the coalescence of the two posterior cornua along their inner borders, where, being increased in breadth, they meet each other in the middle line (see Plate XX. fig. 1). In consequence of this arrangement, the *substantia gelatinosa* extends uninterruptedly and horizontally across from one side to the other. From the posterior white columns it is separated, particularly on each side, by a kind of border composed of fine nerve-tubes, which wind round it and proceed from the posterior roots of the nerves.

The anterior grey substance, on the other hand, is here, as in other regions of the chord, separated by the anterior white columns into two cornua of considerable size. These curve somewhat inwards, taper to an irregularly rounded point, and nearly reach the circumference of the chord.

Here also the spinal canal is very distinct and large, being the $\frac{1}{100}$th part of an inch in diameter. It is situated much nearer the anterior than the posterior surface of the chord*.

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* This mode of preparation succeeds best in cold weather; for in summer, the chord, however fresh when immersed in the spirit, remains more or less spongy, instead of becoming firm and dense in the course of five or six days. The spirit should be diluted with an equal quantity of water during the first day, after which it should be used pure. Certain modifications of this mode of preparation may be sometimes employed with advantage by a practised hand.

The nerve-vesicles however are few in number, and scattered irregularly through the grey substance. They are not, as in some other regions, collected into large masses, but are most numerous in the anterior cornua, at the extremities of which three or four may be seen closely grouped together.

Nature and Arrangement of the Nerve-fibres in the Grey Substance of the Spinal Chord.

The nerve-fibres in the grey substance of the spinal chord are mostly of the white tubular kind, and of variable but small average diameter†. With regard to *direction*, they may be divided into two classes,—*transverse* and *longitudinal*.

Transverse Fibres.—These again may be divided into two orders,—*antero-posterior* and *latero-transverse*.

Antero-posterior Fibres.—On each side of the middle line, in the posterior grey substance, are several large bundles of fine nerve-tubes, which take a transverse direction from behind forwards (see Plate XX. fig. 1). These bundles may be traced through the posterior white columns, partly into the roots of nerves which arise in the same vertical (in Man, horizontal) plane, and partly into others above and below them. They are convex towards the middle line, but on approaching the anterior cornua, they break up into smaller bundles, which interlace with each other and form a coarse network, in the meshes of which the nerve-vesicles are contained. Many of these nerve-tubes, both singly and in bundles, extend outwards into the antero-lateral white columns‡. Many of them, also, appear to be continuous with the anterior roots of the nerves; but whether they be so or not, the anterior and posterior roots are mingled together in the network above mentioned§. Between the spinal canal and the anterior median fissure, some of these fibres cross obliquely through the anterior white columns, and decussate with corresponding fibres from the opposite side (see Plate XX. figs. 1, 3, &c.).

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* As stated by Stilling and Wallach, it extends uninterruptedly through the whole length of the medulla spinalis. In many preparations that I have by me of the filiform extremity of the chord, where it measures less than a line in diameter, the spinal canal is even larger than in other regions.

† By Drs. Stilling and Wallach they are described as grey fibres, but seem to have been examined under strong pressure. Moreover, they ought to be examined in a perfectly fresh state, as spirits of wine considerably alters their appearance.

‡ After nearly reaching the circumference of the chord, they *appear* to form with each other a series of loops of various sizes; but of this arrangement I cannot speak with any confidence, for it is seen only in a section of a perfectly fresh chord, and under strong pressure, to which the appearance may be due. Stilling (Textur des Rückenmarks, p. 21) also states that the transverse (so-called) *grey* fibres form loops at the periphery of the chord, but since he made use of strong compression, his statement is open to the same objection.

§ This description corresponds, in some measure, with that given by Dr. Stilling (Ueber die Medulla Oblongata, p. 4), who states that the posterior nerves, after forming loops within the grey substance, become continuous with the anterior roots. I have never seen loops such as he describes, but the rest of his statement is probably correct; for although it is impossible to trace any *single* fibre from the posterior to the anterior roots, it is nevertheless certain that the latter are continuous in the grey substance with *bundles* which proceed from the former. According to Stilling, therefore, the anterior and posterior roots of the spinal nerves are united in the grey substance by intervening *grey* fibres, since all the transverse fibres are described as such; or to use

Latero-transverse Fibres.—The second order of transverse fibres take a more or less horizontal direction between the opposite sides of the grey substance, forming the transverse commissure, and are arranged chiefly in loose bundles (see figs. 2 and 3). Those behind the spinal canal diverge on each side into the anterior and posterior grey masses, and extend into both the posterior and lateral white columns; a great number being evidently continuous with both the anterior and posterior roots of the nerves. One large bundle, in the centre, is particularly conspicuous (see figs. 2 and 3). Those in front of the spinal canal are much less numerous and curve principally forwards: they may be traced partly into the antero-lateral columns, and partly into the anterior roots of the nerves.

By Dr. Stilling some of the fibres of the posterior nerves are said to cross over, behind the spinal canal, into the anterior cornua of the opposite side. I have many times thought that such an arrangement really exists, but the inquiry is attended with great difficulty, and my own observations, though frequently repeated, are too uncertain in their results to admit of my confirming or denying the existence of these fibres. Hanover denies that there is any crossing of the fibres in the spinal chord. He says, "Une partie des fibres passe bien d'un côté de la moëlle épinière à l'autre, mais un entre-croisement géneral n'a pas lieu[*]."

Longitudinal Fibres.—The fibres of the *substantia gelatinosa* are, as usually described, chiefly longitudinal. When examined immediately after death, and uninjured by pressure or traction, they have all the characters and appearance of minute tubular fibres, presenting dark, single, and sharply-defined outlines, with frequent varicosities; but when stretched, or otherwise injured by manipulation, they lose their dark borders, and become exceedingly pale and delicate[†]. They vary but little in size, but are all extremely slender, their average diameter not exceeding the $\frac{1}{10,000}$th of an inch: some few are larger, but I have seen numbers as small as the $\frac{1}{15,000}$th or $\frac{1}{16,000}$th of an inch in diameter, as shown by the micrometer. They are usually distinguished as grey fibres, but differ in many respects from the grey fibres contained in the sympathetic system of nerves; for they are not only, on an average, finer, but, like the tubular fibres, are little or not at all affected by acetic acid, which fails to bring out any traces of nuclei[‡]. They have also been said to resemble the processes of the

his own words "Die Primitivfasern der Nervenwurzeln nichts Anderes sind als die unmittelbaren Fortsatze der queerlaufenden grauen Substanz des Rückenmarks" (Textur des Rückenmarks, p. 28). The transverse fibres, however, are really white tubules of smaller diameter than those which form the roots of the nerves.

[*] Recherches Microscopiques sur le Système Nerveux, p. 14.

[†] The method adopted for examining these fibres was as follows:—a thin longitudinal section through the *substantia gelatinosa* was made by a rapid stroke with a very sharp instrument, wet with albumen. The *substantia gelatinosa* was then carefully separated from the parts on either side of it, and examined without any pressure beyond that produced by the weight of the thin glass employed to cover it.

[‡] Remak states that they are nucleated. Drs. Stilling and Wallach describe them as grey nerve-tubes

caudate vesicles, but in their natural state they certainly bear no resemblance to them whatever. Around the extremity of the spongy portion of the posterior cornua, these longitudinal fibres are collected into an arched and very dense band, of the same form, and about the same thickness as the *substantia gelatinosa*, with the lower border of which it is continuous. This band may be seen even with the naked eye, and then appears as a white opake stripe. The longitudinal fibres are also found, but in smaller numbers, through the rest of the grey substance.

Changes in the Form of the Grey Substance.

On examining the chord upwards towards the lumbar enlargement, certain modifications are found to take place in the form and disposition of the grey masses. The two halves of the posterior mass, with its two sets of antero-posterior bundles of tubular nerve-fibres, begin to separate from each other at the middle line (see figs. 2 and 3). Here the *substantia gelatinosa* is first interrupted, and the posterior border of the grey substance between its divided central extremities, or rather, the posterior fibres of the transverse commissure, begin to arch forwards towards the spinal canal, and to mark out the rudiments of the posterior cornua. At the same time, on each side, and a little behind, the spinal canal, a small but gradually increasing mass of caudate vesicles makes its appearance. These are the commencement of two longitudinal columns of vesicular substance, which extend through the whole length of the spinal chord, and which I name the *posterior vesicular columns.* They are traversed and surrounded by fibres from the posterior roots of the nerves, and also by arched fibres of the posterior transverse commissure, some of which, as already stated, are continuous with the anterior roots of the nerves. The changes just described continue to increase from below upwards, and reach their greatest extent in the middle of the lumbar enlargement, where the posterior cornua are broad and long, and widely separated from each other by the posterior white columns of the chord; while the space between the posterior border of the transverse commissure and the spinal canal, and which is almost entirely occupied by the former structure, is much reduced in breadth, for it measures only the $\frac{1}{230}$th of an inch, whereas at the lower extremity of the chord its diameter reaches the $\frac{1}{50}$th of an inch (see Plates XX. and XXI. figs. 1 and 6). At this central constricted portion, therefore, of the transverse commissure, its fibres, which before were but loosely arranged, are now compressed into a dense band, but still diverge on each side into the anterior and posterior cornua. In consequence of these changes, also, the two *posterior vesicular columns*, which have increased considerably in size, and were formerly situated behind, and at the sides of, the spinal canal, are now pushed up, as it were, and included in the

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presenting a very small diameter and a bright golden colour; but add, that they are not easily examined with accuracy. Repeated and careful examination, however, has convinced me that the above description is correct; their golden colour, when seen by transmitted light, is due only to the granular matrix in which they lie; when viewed by direct light, they have an opake white appearance.

posterior cornua, some of their vesicles reaching as high as the *substantia gelatinosa*. As a further result of the same changes, the posterior white columns are much deeper and broader here than in the lower regions of the chord (compare Plates XX. and XXI. figs. 3, 4, 5 and 6).

While the posterior masses of the grey substance are undergoing the modifications just described, a series of somewhat similar alterations are found to take place in the form and arrangement of the anterior masses. In the middle of the lumbar enlargement, the anterior cornua have increased to a still greater extent than the posterior, and have assumed a shape the opposite of that which they possessed lower down in the chord. They now turn rather outwards instead of inwards, and have a large, irregularly club-shaped, instead of a pointed, extremity. The caudate vesicles have become exceedingly numerous, and are grouped together in several large masses, which are situated chiefly on the outer and middle parts of the cornua (fig. 6). They lie in the meshes of a net-work formed by bundles of fibres proceeding from the anterior and posterior roots of the nerves, and from the commissural bands behind the spinal canal*.

On proceeding upwards from the lumbar enlargement into the dorsal region of the chord, arrangements in the grey substance are observed to take place in the reverse order of those already described. By degrees the posterior cornua are reduced in length, and somewhat modified in shape; their inner sides extend towards each other and the middle line, while the posterior bands of the transverse commissure are drawn, as it were, gradually backwards, becoming at the same time less curved; so that the space between them and the spinal canal is now correspondingly increased. Into this space the two *posterior vesicular columns* advance between the fibres of the transverse commissure, together with the inner sides of the posterior cornua, which, in the middle of the dorsal region, coalesce and inclose them behind. (Compare Plates XXII. and XXIII. figs. 7, 8, 9 and 10.). Here, then, the posterior grey substance again consists only of a single mass, and again, also, the *substantia gelatinosa* extends uninterruptedly and nearly horizontally across from side to side. On the other hand, the anterior cornua are long, straight and narrow, and project almost directly forwards. The caudate vesicles, reduced considerably in number, are scattered irregularly through them, but are more numerous towards their extremities, where they are sometimes seen in the form of one or two small groups.

From the middle of the dorsal region to the cervical enlargement of the chord, the alterations in the form of the grey substance are once more reversed, being nearly similar to those which are found to take place on proceeding upwards from its lower extremity. The posterior mass renews the process of division into two parts, commencing with the *substantia gelatinosa* at the middle line, where the transverse commissural bands are gradually pressed, as it were, forwards, and thus mark out the posterior cornua; while in these, which again reach their greatest size in the middle of the cervical enlargement, the *posterior vesicular* columns, formerly situated behind, and at the sides of the spinal canal, at length resume their position and increased dimensions (see fig. 11). During the progress of these changes, the anterior cornua also undergo considerable modifications. They become gradually broader and longer, and contain a much larger number of vesicles, which in the cervical enlargement are grouped together, as in the lumbar region, into several large masses; indeed, the general arrangements of the grey substance at these two parts of the chord have a very striking resemblance*.

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* It is interesting, in a physiological point of view, to find that the number of caudate vesicles is in direct proportion to the size of the nerves, which are known to be much larger at the lumbar and cervical enlargements than in other regions.

At the outer border of the grey substance, between the anterior and posterior cornua, is a small column of vesicular matter, which is softer and more transparent than the rest. This consists of caudate vesicles of inferior size and more regular shape than those usually found in the spinal chord. It is seen distinctly at the upper part of the lumbar enlargement (see Plates XXII. and XXIII. figs. 7 and 8 *m*), and increases somewhat in size in the dorsal region, where it projects slightly into the lateral column on each side. In the cervical enlargement it is less distinctly marked, but higher up it again becomes conspicuous, and is there seen to form the principal part of the nucleus of the spinal-accessory nerve (see fig. 12). On ascending the medulla oblongata, this column of vesicles gradually makes its way inwards till it reaches the space immediately behind the spinal canal, where it meets and blends with its fellow of the opposite†.

In the upper part of the cervical region the posterior cornua are long and narrow. The outer part of each, below the *substantia gelatinosa*, consists of a large and remarkably beautiful network of blood-vessels, which incloses in its meshes bundles of fibres of the lateral columns (see Plate XXIV. fig. 12). These bundles are of various sizes, and encroach gradually upon the cornua as they ascend to the medulla oblongata. Some of the fibres of the spinal-accessory nerve run transversely through this network; but a considerable branch, on entering the grey substance, bends *forwards*, and after passing through its vesicular nucleus, continues the same course *within the anterior cornu, where its fibres traverse and surround the caudate vesicles, in company with the roots of the anterior spinal nerves* (see Plate XXV. fig. 13). The space behind the spinal canal has slightly increased in breadth, and the *posterior vesicular columns* on each side of it have nearly the same position and relations as in the dorsal region. The anterior cornua are rather small and pointed, and contain each a circular or oval mass of vesicles.

The central portion of the grey substance surrounding the spinal canal is described by FOVILLE[*] as the grey commissure of the chord; and by STILLING[†] as a circular commissure composed of exceedingly delicate grey nerve-fibres. To me, however, its structure appears to consist of a circular layer of extremely fine fibrous tissue (for supporting the sides of the canal), left unobscured by the transverse commissural fibres which arch round it in front and behind. Indeed, it may be seen, at some parts of the chord, to be continuous with the areolar tissue which extends from the borders of the anterior fissure, through the white columns, in front of the canal. It varies, also, in shape at different parts of the chord, being fusiform from side to side in the higher regions, where the curves described by the anterior and posterior transverse commissures are least; and nearly circular in the lower regions, where those curves are greatest. The walls of the spinal canal are lined with a layer of columnar epithelium, which in a transverse section of the chord, viewed by direct light, appears as a white opake ring at the margin of the foramen[‡].

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* The vesicles are more abundant, however, in the lumbar than in the cervical enlargement, and therefore correspond in number to the relative size of the nerves which belong respectively to these regions.

† The nucleus of the spinal-accessory nerve in the medulla oblongata has been already correctly described by Dr. Stilling, Die Medul. Oblong.

Of the Nerve-vesicles of the Spinal Chord.

The vesicles found in the grey substance of the spinal chord are either circular, oval, pyriform, or otherwise irregular in shape; and all of them, except those peculiar to the *substantia gelatinosa*, have remarkably delicate processes issuing from their sides, like the neck from a flask or funnel (see Plate XXV. fig. 15). They are found chiefly in the anterior cornua and in the *posterior vesicular columns*[§]. They are also connected with each other by their processes, which divide and subdivide into smaller branches, so that the space between them appears to be occupied by a minute network of the most delicate fibrils[||]. Many of these processes, particularly from vesicles situated near the border of the grey substance, run out into the white columns, through fissures which contain blood-vessels and pia mater. Whether they give off branches which follow the vascular network through the white columns, I have not been able to determine. That the caudate vesicles have some important relation to the functions of the nerves, there is every reason to believe, since we find that they not only *invariably exist in the vicinity of nerves*, but, as already shown, that *they increase also in number in direct proportion to the size of the nerves with which they are associated.* I am aware that several continental physiologists of eminence assert that they have discovered in the lower vertebrata and in the invertebrata a direct union between the caudate vesicles and the tubular fibres; but I have never been able to make out satisfactorily any such connection in the spinal chord of mammalia, although I have constantly sought for it under very favourable circumstances*. The nerve-fibrils wind around, and apparently in contact with, the vesicles, but the connection does not seem to have at all the character of an attachment. Nor have I succeeded in tracing anything like continuity between the tubular fibres and the *processes* of the vesicles. It is very common to see one or two of these processes running outwards into a bundle of nerves attached either to the anterior or posterior cornua; but then we have seen that they pass out into the white columns from *all* sides, and therefore from parts which are not connected with nerves.

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[*] Traité Complet de l'Anatomie, &c. du Système nerveux Cerebro-spinal.

[†] Textur des Rückenmarks, p. 23.

[‡] It was suggested to me by Mr. BOWMAN, of King's College, that as the spinal canal is continuous with the fourth ventricle, it is probably lined with epithelium, which, on careful examination, I found to be the case.

[§] The situation and connections of these two longitudinal columns of vesicular substance render them extremely interesting. They would seem to have some intimate relation to the functions of the posterior roots of the nerves, many of which, as already stated, traverse and surround them, without, however, forming with their vesicles any apparent connection. At the upper part of the medulla oblongata they are reduced in size and ultimately disappear. The processes radiate from their vesicles on every side; some extending to the extremities of the posterior cornua, and others into the lateral and posterior white columns.

[||] A somewhat similar description is given by TODD and BOWMAN, Physiological Anatomy, p. 214.

Blood-vessels of the Spinal Chord.—These enter through the anterior and posterior median fissures, through the smaller fissures in the white columns, and at the roots of the nerves. After giving off numerous branches to the white columns, they proceed inwards to the grey substance, along the whole periphery of which they form a remarkably beautiful network of loops†, intermixed with nerve-tubes and some of the processes of the vesicles. Within the grey substance they form an extremely minute network. Some of the vessels which enter at the anterior and posterior fissures and at the posterior white columns, anastomose with each other around the spinal canal; while others branch off, right and left, between the bundles of the transverse commissure, into the anterior and posterior cornua, where they follow the course of the transverse fibres, and running to the periphery of the grey substance, assist in forming there the loops already described. A series of loops is also found to exist near the extremity of the posterior cornua, along the border of the spongy substance.

Of the White Columns of the Spinal Chord.

The anterior white columns of the chord have no proper transverse commissure, but are united in the middle line, at the bottom of the fissure, by a fibrous band or raphè. In this situation, however, they are crossed transversely by horizontal and oblique tubular nerve-fibres and blood-vessels proceeding from the grey substance on either side, and which, in some regions of the chord, are so numerous that they nearly replace the longitudinal fibres‡. The transverse slits observed by Foville on each side of the raphè are fissures for the passage of blood-vessels.

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* Hanover is, I believe, the only observer that professes to have seen it in all classes of vertebrata.

† According to Dr. Stilling this network consists of the (so-called) grey transverse fibres. He confesses, however, that it is not unlike a network formed of small blood-vessels.—Textur des Rückenmarks, p. 22.

‡ Stilling maintains that the separation of the anterior white columns is complete, for at the bottom of the fissure may be seen "the transverse grey fibres of the anterior commissure."—Ueber die Medul. Oblong. p. 6. The fibres, however, which give to this structure its grey or yellowish-grey appearance, are really blood-vessels and pia mater.

Nor are the posterior columns of the chord connected by a transverse commissure; for the posterior fissure, as stated, first, I believe, by Bellingeri[*], reaches down to the border of the grey substance, or rather, to the posterior border of its transverse commissure, which has been mistaken and described by Foville as a commissure between the posterior white columns, formed by their coalescence at the bottom of the fissure[†].

Of the Origin of the Spinal Nerves.

Posterior Roots.—The bundles of fibres which form the posterior roots of the spinal nerves are much larger, but less numerous, than those of the anterior; the fibres themselves, however, are mostly finer and more delicate[‡]. They are attached immediately to the *posterior* white columns *only*[§], which they traverse obliquely inwards, interlacing and forming with each other an intricate plexus (see figs. 6 and 14). From this plexus straight and distinct bundles[||] enter the posterior cornua along their whole breadth, and cross the *substantia gelatinosa* both obliquely and at right angles; some being immediately continuous with fibres of the transverse commissure, while others, after plunging into the spongy portion of the cornua to unequal depths, break up and form a finer net-work which extends forwards into the anterior cornua: some of their fibres, after traversing the grey substance, pass out, as already described, into the posterior and lateral white columns.

Anterior Roots.—These are attached exclusively to the anterior parts of the antero-lateral columns. They do not always enter the chord directly, or at the points of attachment, but sometimes run for a short distance transversely along its circumference (see Plate XXI. fig. 6). They then traverse the antero-lateral columns somewhat obliquely, and in straight and distinct bundles, which do not, like those of the posterior nerves, cross and interlace each other, but proceed directly to the anterior grey cornu*. Their connection with the latter is still doubted by many physiologists of eminence, but in the preparations which illustrate this paper, it may be seen as clearly and satisfactorily under the microscope, as their connection with the white columns is perceived by the naked eye†. On reaching the grey cornua, they break up into smaller bundles and separate fibrils, which diverge in various directions. Some of the fibres proceed to the right and left, crossed by others from neighbouring bundles (see Plates XXIII. and XXV. figs. 14 and 15). Of those proceeding within the external border of the cornu, a few pass out to the antero-lateral columns; while others, after winding round groups of caudate vesicles, curve inwards and join the fibres of the transverse commissure. Of those proceeding along the inner border of the cornu, a few pass into the white column at the side of the median fissure; while others, on reaching its base, curve round, and, in company with fibres from the posterior cornu, cross obliquely through the junction of the anterior columns in front of the spinal canal, where they decussate with corresponding fibres from the opposite side. The remaining bundles of the roots plunge into the central portion of the cornu, and winding among its vesicles, are lost in the intricate network (see fig. 14). A few of their fibres, after proceeding to some depth in the grey substance, bend round and take a more or less longitudinal direction.

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[*] De Medullâ Spinali, pages 7 and 8.

[†] He observes "Elle semble plutôt la simple coalescence des deux faces latérales, réunies au fond du sillon." *Op. cit.* p. 134.

[‡] I find that this statement coincides with that previously made by Remak (Müller's Archiv, 1836) and by Henle, Allg. Anat. p. 669.

[§] I believe that this statement is directly opposed to the opinions of almost every anatomist, except Sir Charles Bell, that has written on the subject of the spinal chord; and were it not undeniably proved to be true by the preparations which accompany this paper, I should feel some hesitation in coming forward to oppose so many eminent and recent authorities. According to Bellingeri (*op. cit.*) the posterior roots are attached to both the posterior and lateral, and the anterior roots to the anterior and lateral, white columns. Mr. Grainger and Mr. Swan join in referring the origin of both to the lateral columns only: the former observes (Spinal Chord, p. 30), "I have never been able to trace any fibres from the nerves into the fasciculi composing the anterior and posterior columns." A nearly similar statement is made by Dr. Todd. The two other most recent writers on the subject (Drs. Sharpey and Carpenter) have adopted the same views as Bellingeri. By Sir C. Bell (whose conclusion, however, was probably drawn from superficial examination) these roots are referred to the posterior columns only. "Each nerve," says he, "has two distinct series of roots coming out in packets or fasces, one from the posterior column, and one from the anterior column, of the spinal marrow."—Nervous System, p. 29, 4to.

[||] The primitive fibres of most of these bundles are very small, their average diameter being about the $\frac{1}{7000}$th of an inch; a few very large tubules are found amongst the rest, and here and there is seen a slender bundle composed of fibres of larger average size. The anterior roots of the nerves within the grey substance are composed of fibres of more irregular size, and contain a much greater number of large tubes than those of the posterior roots.

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* I have not yet ascertained whether any of the fibres of the spinal nerves ascend with the white columns without entering the grey substance, as maintained by Mr. GRAINGER, Mr. SOLLY, and Dr. J. BUDGE.

† Dr. SHARPEY, one of the most recent authorities on the subject, observes, "The anterior roots have been said to reach the anterior grey cornu, by passing through the superficial stratum of white substance over it, *but actual demonstration of the fact is yet wanted*."—QUAIN's Anat. 5th edit. p. 727. BELLINGERI states merely that some of the anterior roots *perhaps* reach as far as the grey substance. His account of their origin is as follows: "Cernuntur filimenta radicum anteriorum nervorum spinalium partim exoriri à fasciculis anterioribus medullæ spinalis, et quidem filimenta aliqua nervea directè secedunt à superficie medullæ spinalis; alia verò filimenta nervea per canaliculum a piâ matre suppeditatum profundè descendunt in substantiam albidam medullæ, et *fortassè* nonnulla usque ad cineream substantiam perveniunt."—*Op. cit.* p. 50. It is well known that Mr. GRAINGER was the first who professed to have traced the connection of the anterior roots of the nerves with the grey substance of the chord; and that Dr. STILLING has since described and represented it; but the statements of these eminent men failed to convince most of the physiologists of this country. I may take this opportunity, however, of observing, that we are much indebted to Dr. STILLING for having thrown considerable light on some of the most obscure points in the anatomy of the spinal chord and medulla oblongata; and for having originated and suggested new methods of further inquiry. His researches prove him to be not only a skilful, ingenious and laborious investigator, but, in general, a correct and acute observer. The plates attached to his second work, although a little embellished, are, with a few trifling exceptions, exceedingly correct.

Of the Nerve-tubes of the Spinal Chord.

The nerve-tube is endowed with considerable elasticity, and may be drawn out and attenuated to a great extent. It then loses its thick and sharply-defined borders, or double outline, and assumes the appearance of a much finer and more delicate fibre. When partially broken by traction, the two extremities are connected often by one of its borders only, and sometimes only by the axis cylinder, which has then the appearance of an almost imperceptible, shadowy line; in the unbroken portion of the fibre, however, the axis cylinder appears perfectly pellucid.

The following summary of the principal facts described in this paper may perhaps be found useful.

That the posterior grey substance, at the lower extremity, and in the dorsal region, of the spinal chord, consists only of a single mass; and that the *substantia gelatinosa* there extends uninterruptedly across from one side to the other.

That the nerve-fibres of the grey substance, including those of the *substantia gelatinosa*, are not grey fibres bearing nuclei, like those of the sympathetic, but fine tubules.

That two considerable columns of caudate vesicles (which I have named the *posterior vesicular columns*) in intimate connection with the posterior roots of the nerves, extend through the whole length of the chord; commencing small at its lower extremity, increasing in size in the lumbar and cervical enlargements, and terminating at the upper part of the medulla oblongata.

That the number of caudate vesicles, particularly in the anterior grey substance, is in direct proportion to the size of the nerves.

That the column of vesicles into which, in the cervical region, the spinal-accessory nerve may be traced, extends down the chord as far as the lumbar enlargement.

That a considerable branch of the spinal-accessory nerve, after entering the grey substance through the lateral column, may be easily traced to the caudate vesicles of the anterior cornu.

That the spinal accessory is the only nerve immediately attached to the lateral column.

That the posterior roots of the spinal nerves are immediately attached to the posterior white columns only; and the anterior roots to the anterior columns only; but,

That fibres from both these roots, after traversing certain portions of the grey substance, pass out again into the white columns.

That neither the anterior nor posterior white columns are connected by a transverse commissure.

That the central portion of the grey substance immediately surrounding the spinal canal is not a commissural structure, but a layer of fine fibrous tissue for supporting the walls of the canal, which is lined with a layer of columnar epithelium.

Fig. 2

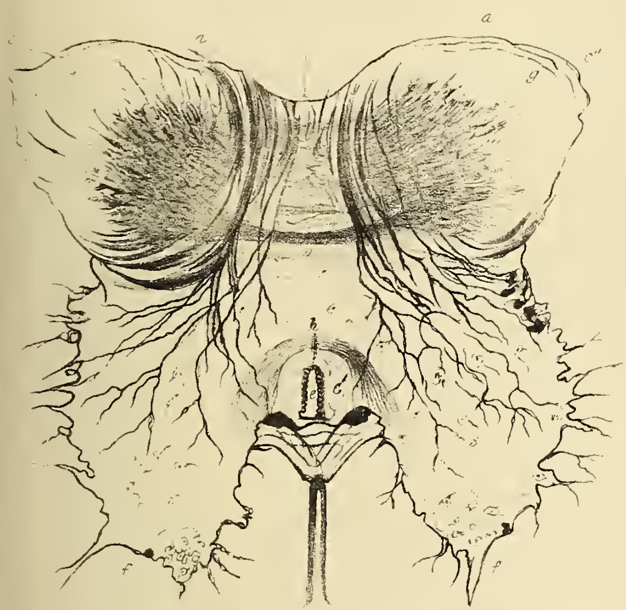


Fig 3

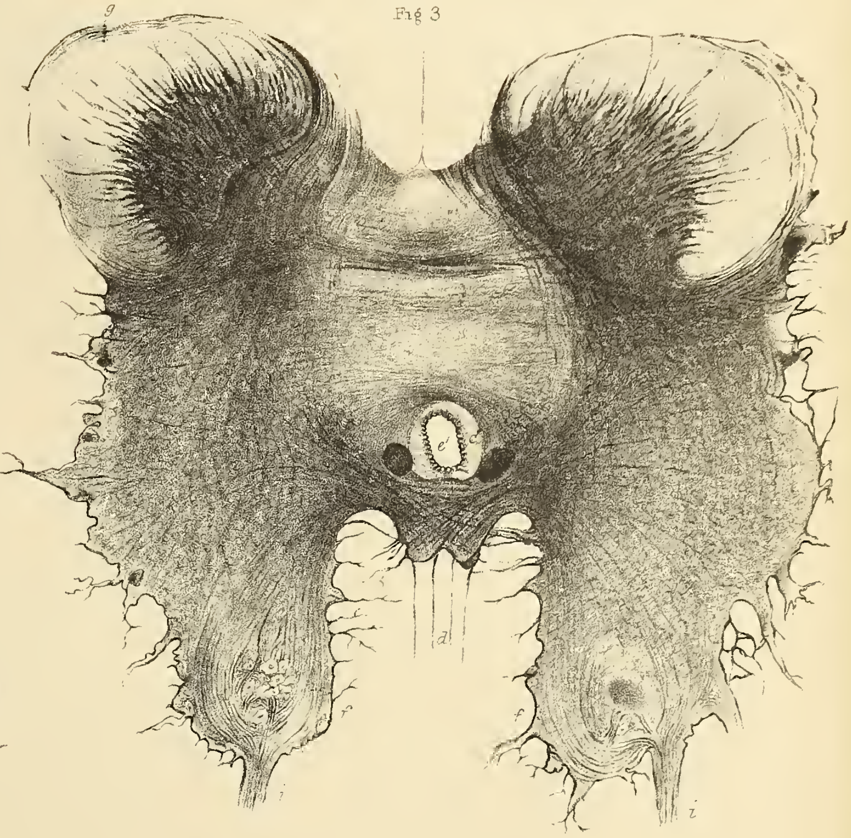


Fig 4.

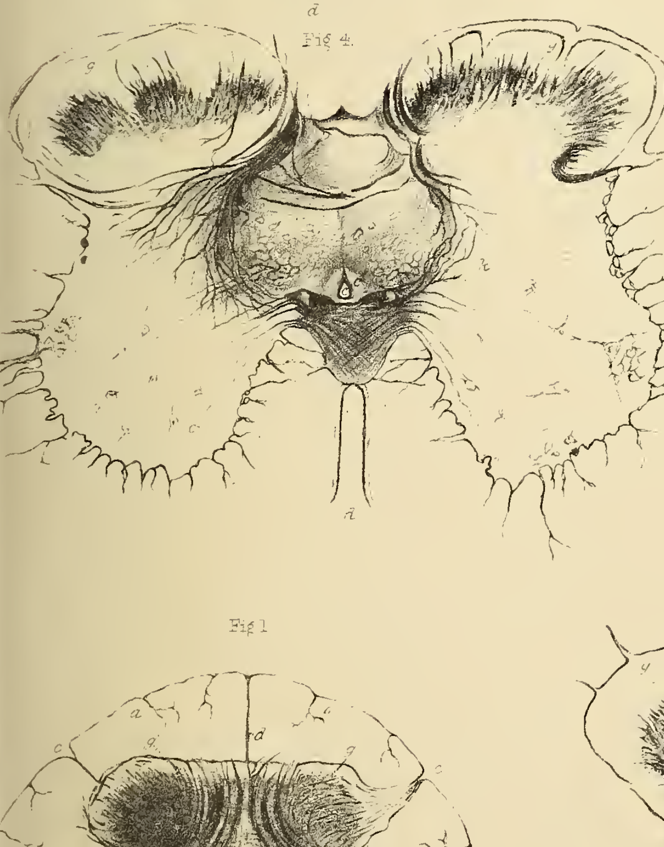


Fig 1

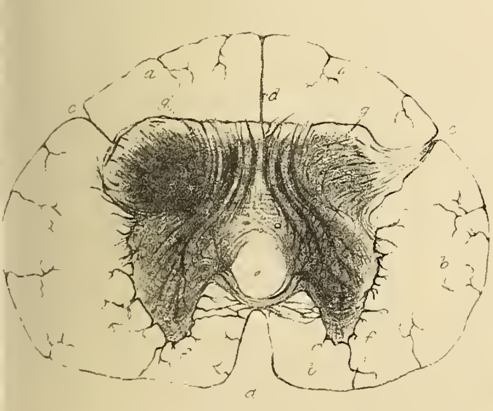
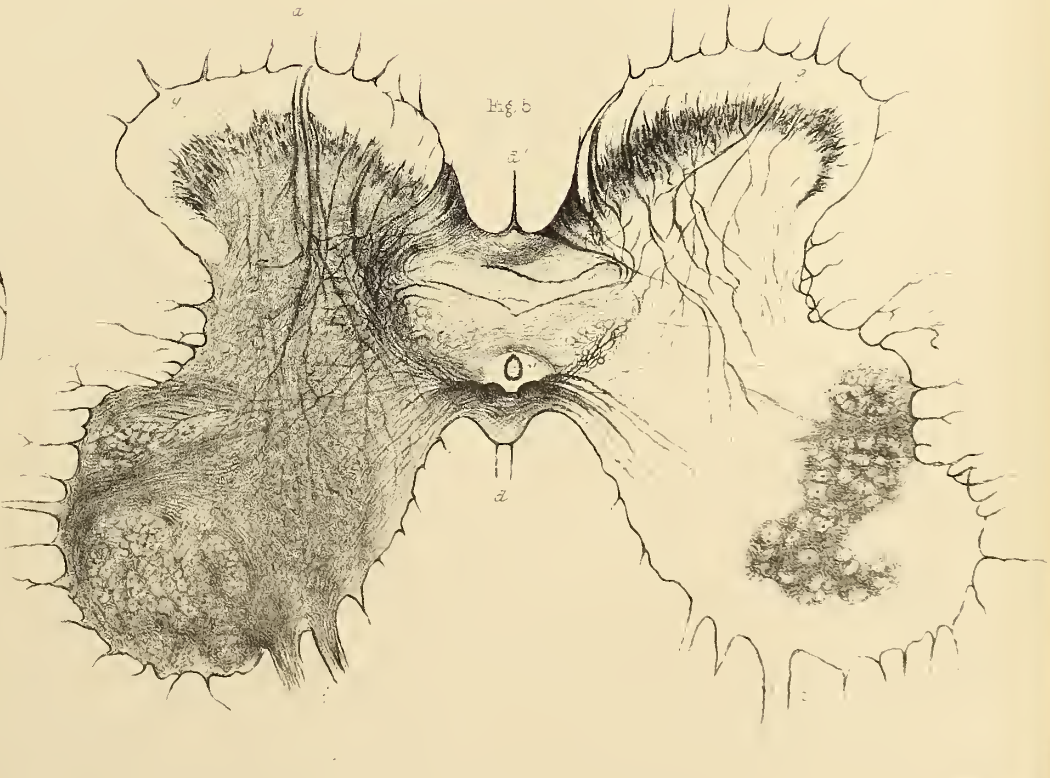


Fig. 5



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I have now stated all that I have to say at present on the subject of the spinal chord; but if the observations contained in this communication be considered by the Royal Society to throw important light on its structure, they will be followed by others that I have made on the medulla oblongata and cerebellum. I cannot conclude, however, without acknowledging the kind interest shown me, during these inquiries, by Mr. SOLLY, Mr. GRAINGER, and Dr. MARSHALL HALL. I am also much indebted to Mr. FREDERICK BROWN (Member of the Microscopical Society) for several ingenious contrivances with which he kindly furnished me.

EXPLANATION OF THE PLATES.

PLATE XX.

The Plates represent transverse sections of the spinal chord of the Calf, all of which, except the two last, were prepared according to the first method described in the paper. The same letters indicate the same parts in all the figures.

Fig. 1. A section of the white and grey substances of the filiform extremity of the chord, scarcely more than one line in diameter; magnified 20 diameters. *aa.* Posterior white columns; *bb.* Antero-lateral columns of one side; *c.* Posterior lateral fissure, which separates the posterior from the antero-lateral white columns; *d.* Anterior median fissure; *d'.* Posterior median fissure; *e.* Foramen; *ff.* Anterior cornua; *gg. Substantia gelatinosa.* On each side of the middle line are seen antero-posterior bundles of fine tubular fibres.

Fig. 2. A section of the grey substance of the chord about an inch higher up; magnified 20 diameters. *h.* Arched band of tubular fibres; *i.* Light space surrounding the foramen and composed of a circular layer of fine fibrous tissue; the margin of the foramen is set with columnar epithelium; *c''.* Rudiments of the posterior cornua; on each side the *substantia gelatinosa* is broad, but is gradually narrowed at the middle line; the dark or spongy portion of the cornua is seen projecting into it like the matted hairs of a brush. This appearance is caused by oblique sections of bundles of nerves and blood-vessels which enter the grey substance in a more or less longitudinal direction, or with various degrees of obliquity; these, together with the bands of longitudinal fibres, are the chief cause of its opacity, and form the principal difference between its structure and that of the *substantia gelatinosa.*

Fig. 3. Represents the same appearances higher up; magnified 20 diameters. The bundles of transverse commissural fibres are distinctly seen, as well as the decussating fibres in front of the spinal canal; the two dark oval masses

behind these latter fibres are sections of thick bundles cut off by them from the anterior white columns; *i.* Anterior roots of the nerves.

Fig. 4. Another section of the grey substance nearer the lumbar enlargement; magnified 20 diameters. The commencement of the *posterior vesicular columns kk,* is seen at the sides of the spinal canal; other vesicles are also seen in the anterior cornua.

Fig. 5. A similar section through the lower part of the lumbar enlargement; magnified 20 diameters. The vesicles in the anterior cornua have considerably increased in number.

PLATE XXI.

Fig. 6. A section of the white and grey substance through the middle of the lumbar enlargement; magnified 20 diameters. The *posterior vesicular columns kk* are here situated within the posterior cornua, traversed and surrounded by fibres from the posterior roots of the nerves *ll,* part of which are seen also to extend as far as the large groups of vesicles in the anterior cornua.

PLATE XXII.

Fig. 7. Outline of a section of the grey substance, through the upper part of the lumbar enlargement; magnified only 10 diameters.

Fig. 9. A similar section through the lower part of the dorsal region; magnified 20 diameters.

PLATE XXIII.

Fig. 8. Another section three-quarters of an inch higher up; magnified 20 diameters.

Fig. 10. Another section of both the white and grey substance, through the *middle* of the dorsal region; magnified 20 diameters.

Fig. 14. A similar section through the lumbar enlargement, prepared according to the second method described in the paper. It represents the course of the fibres of the roots of the nerves, and of the transverse commissures, through the grey substance; the vesicles have been omitted to prevent confusion. The outline is magnified 20 diameters; the fibres were drawn under a power of 100. Notwithstanding the distinctness of the fibrous arrangement here shown, it is to be understood that this figure, like the rest, is not a scheme, but an exact representation of one of the preparations which accompany the paper, as seen under the microscope.

Fig. 6.

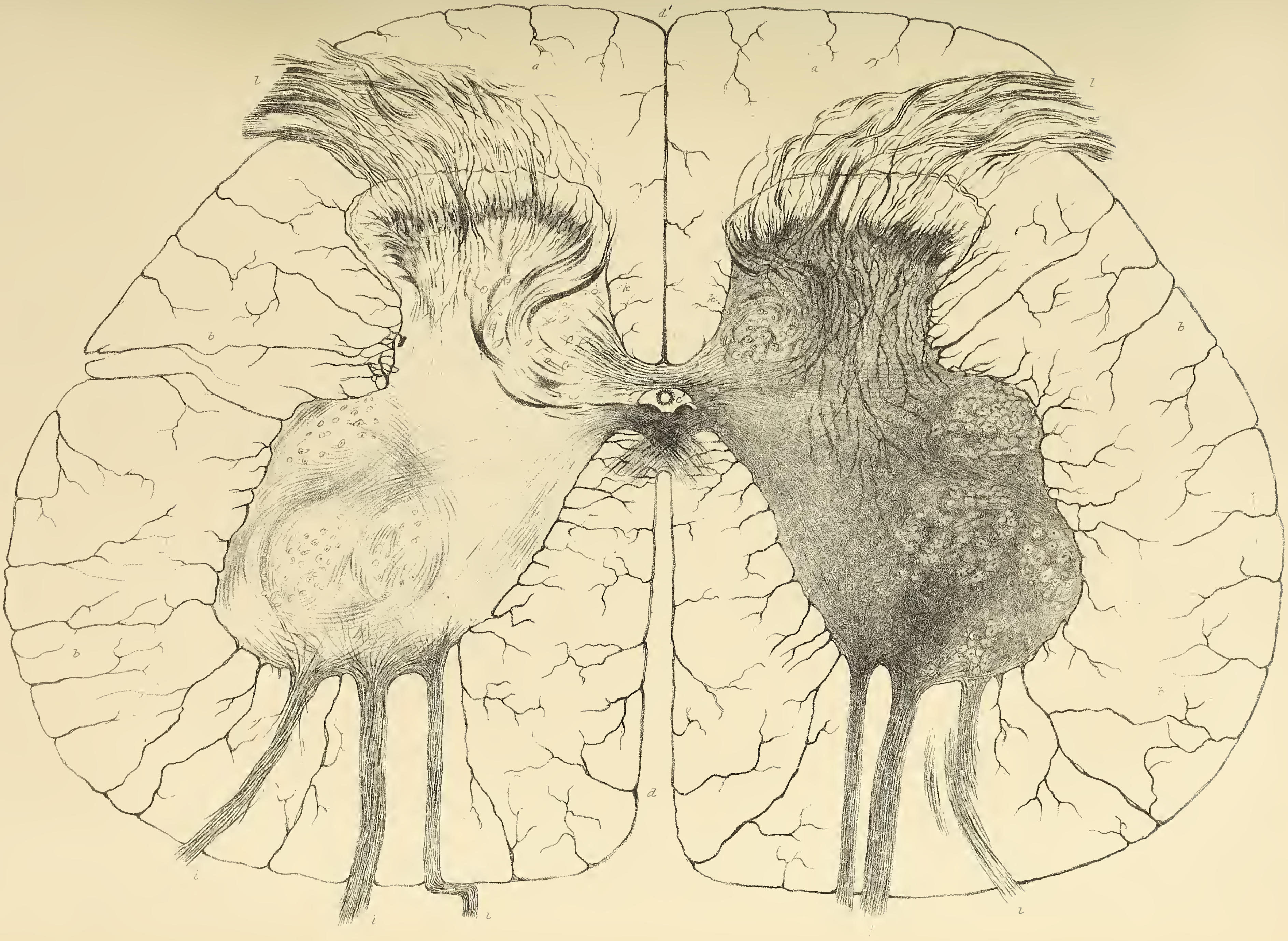

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Fig. 9

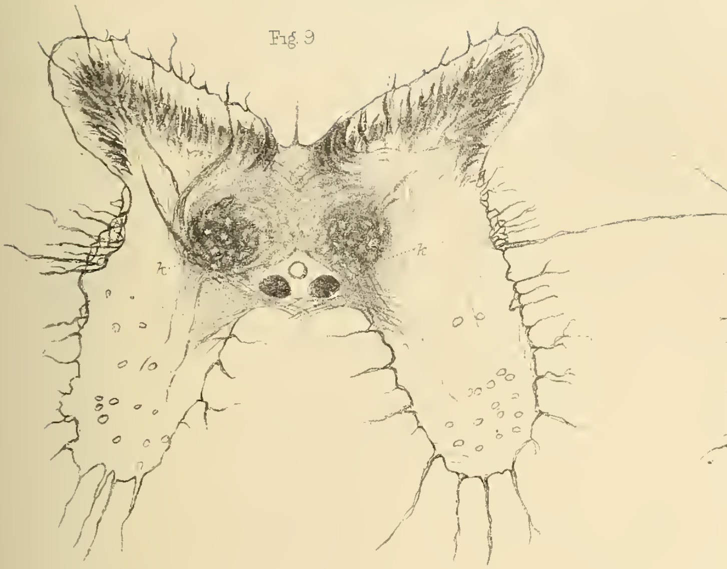

Fig 7.

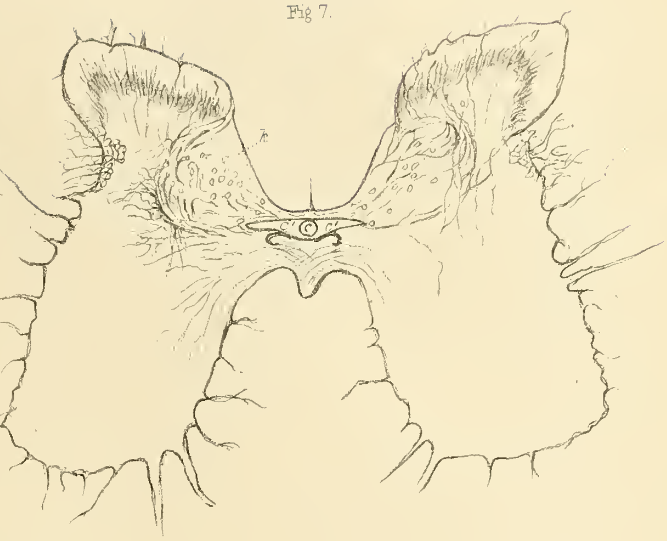

Fig 10.

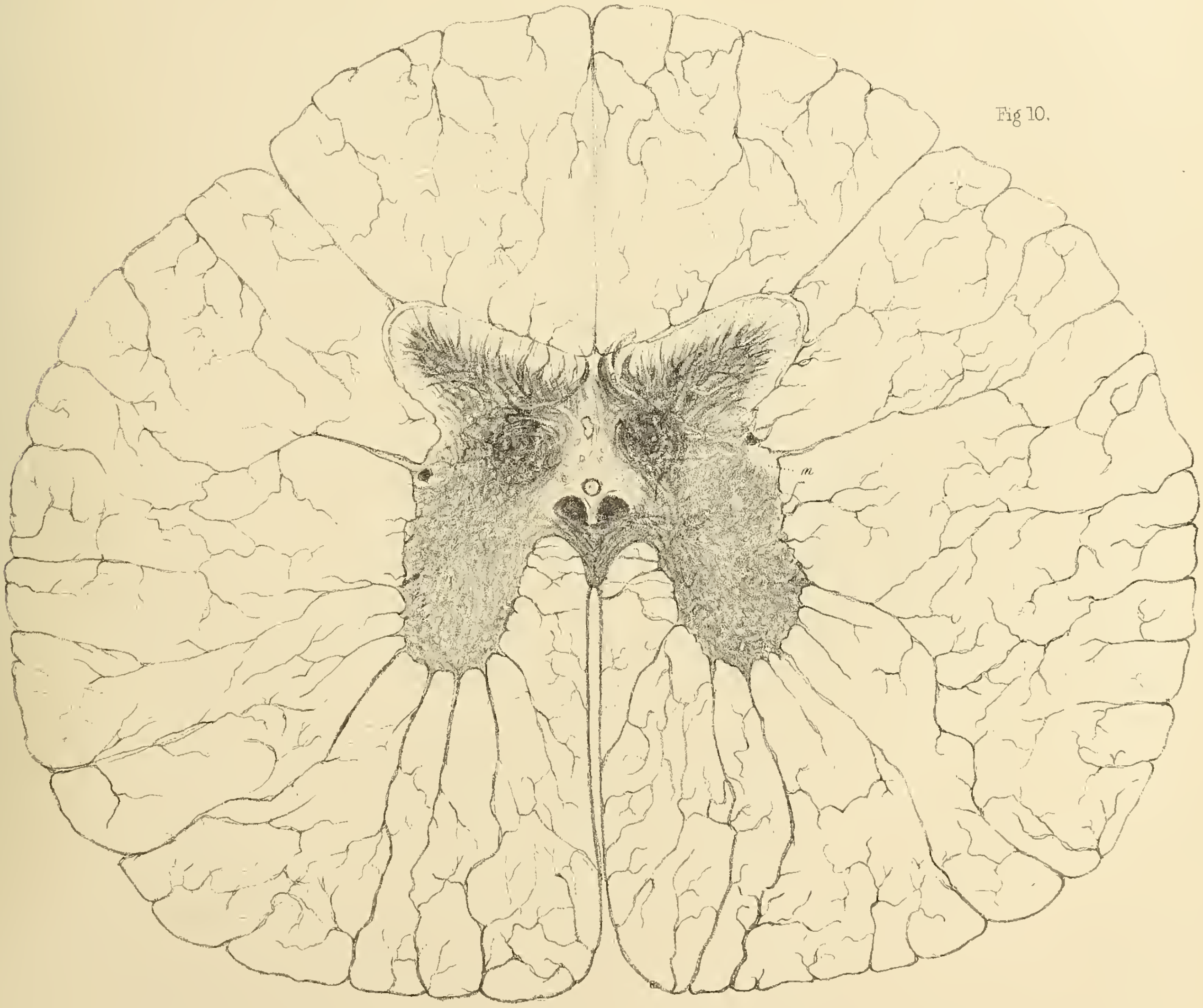

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Fig 8.

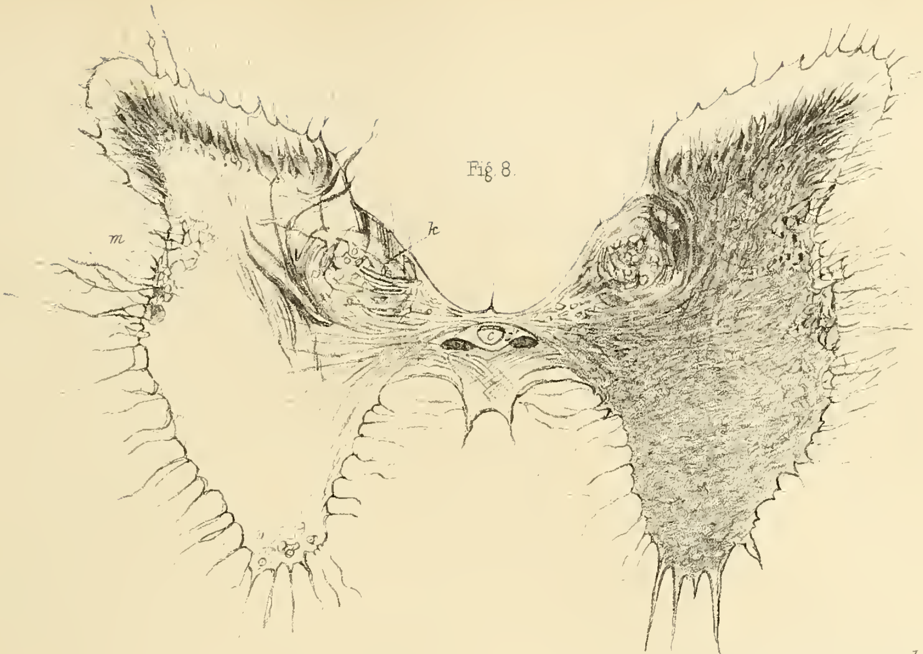

Fig 14.

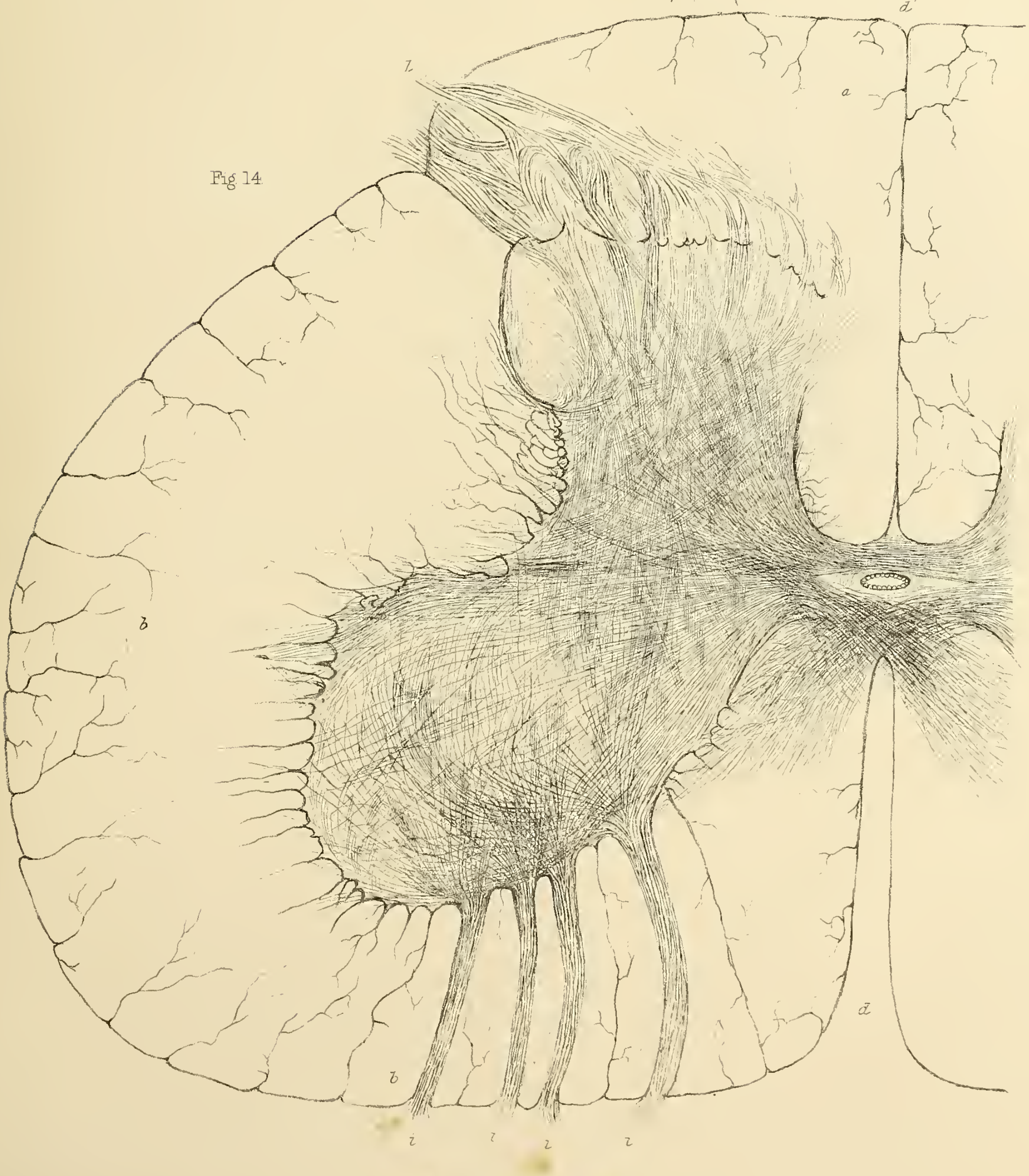

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Fig 12.

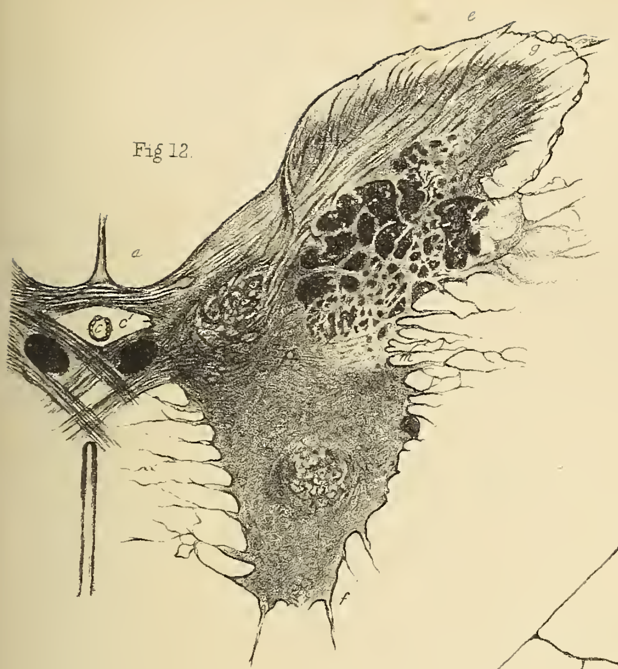
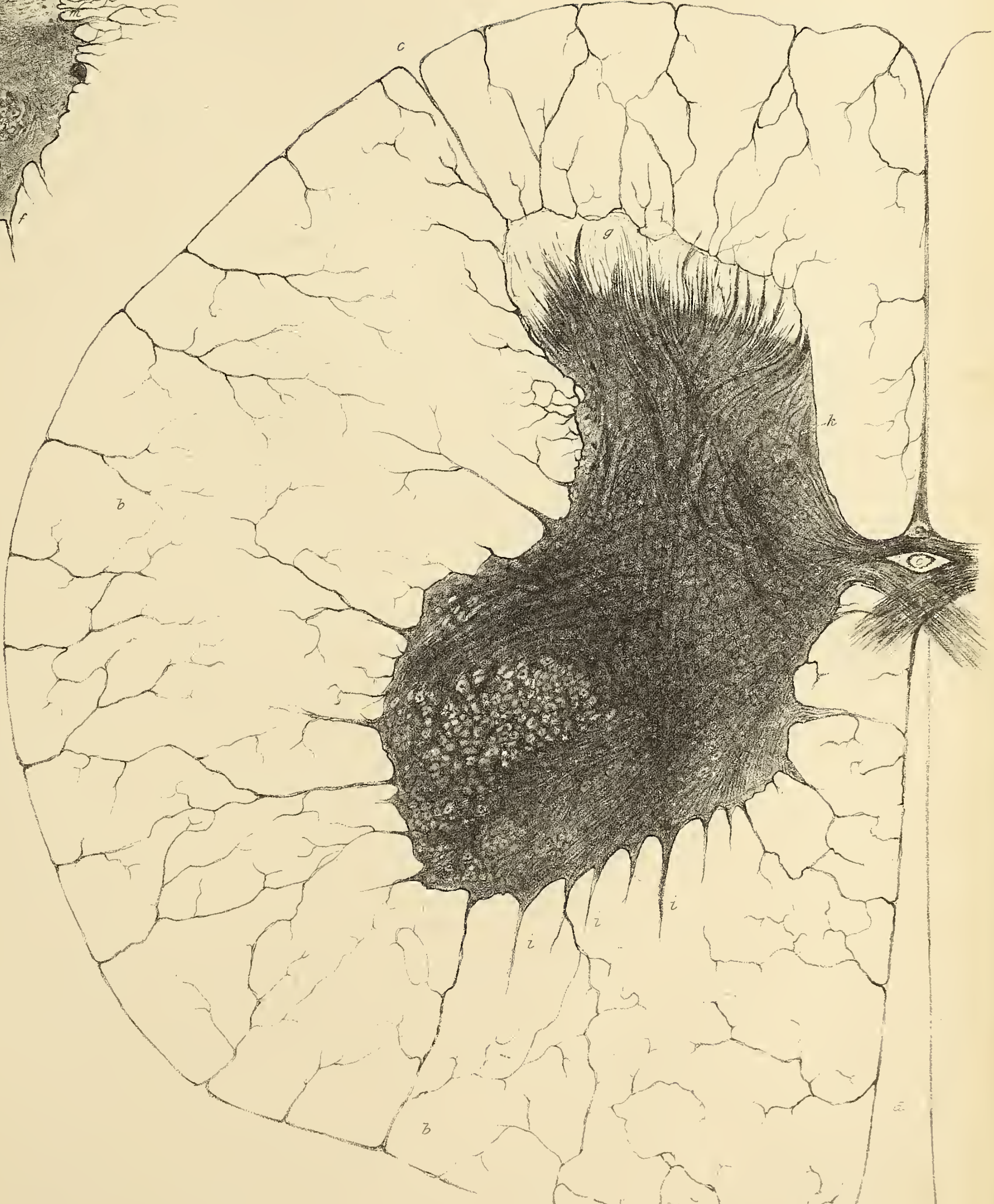


Fig 11.



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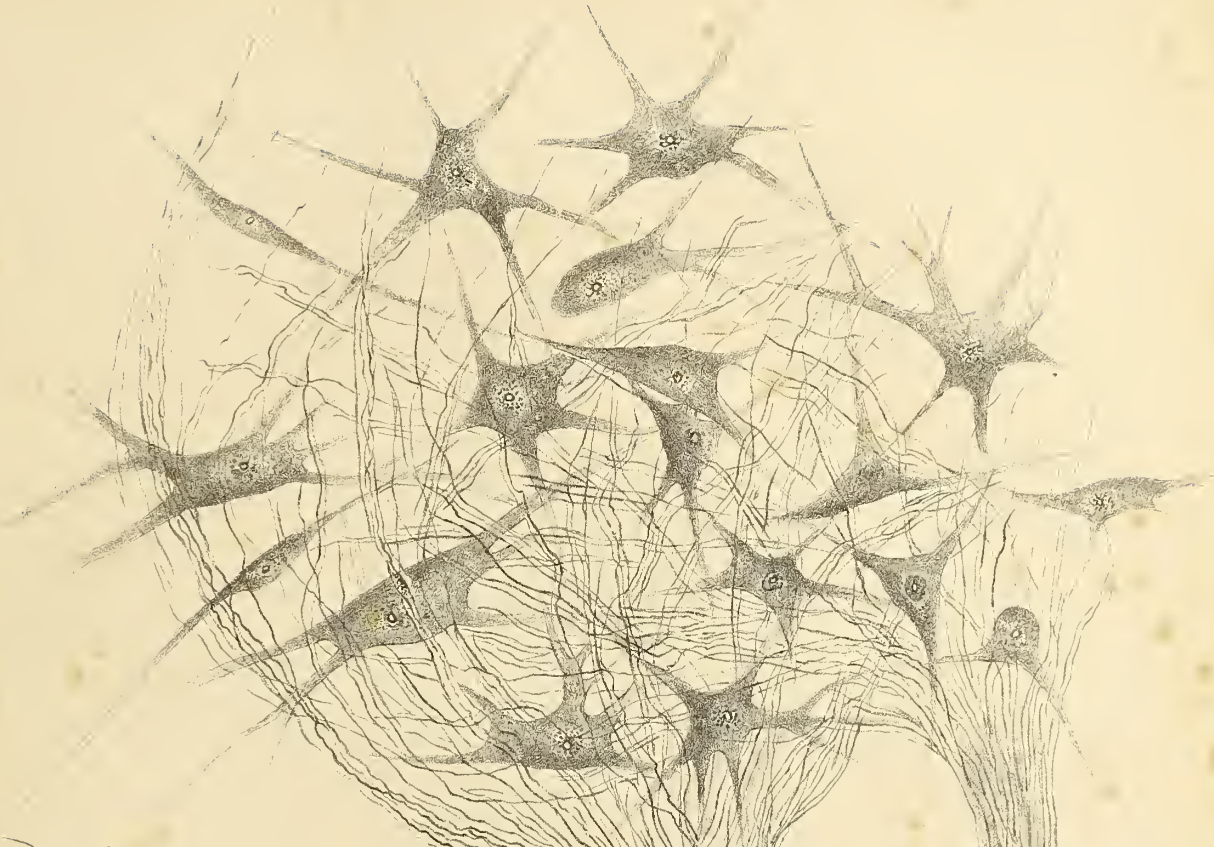

Fig 15.

Fig 13.

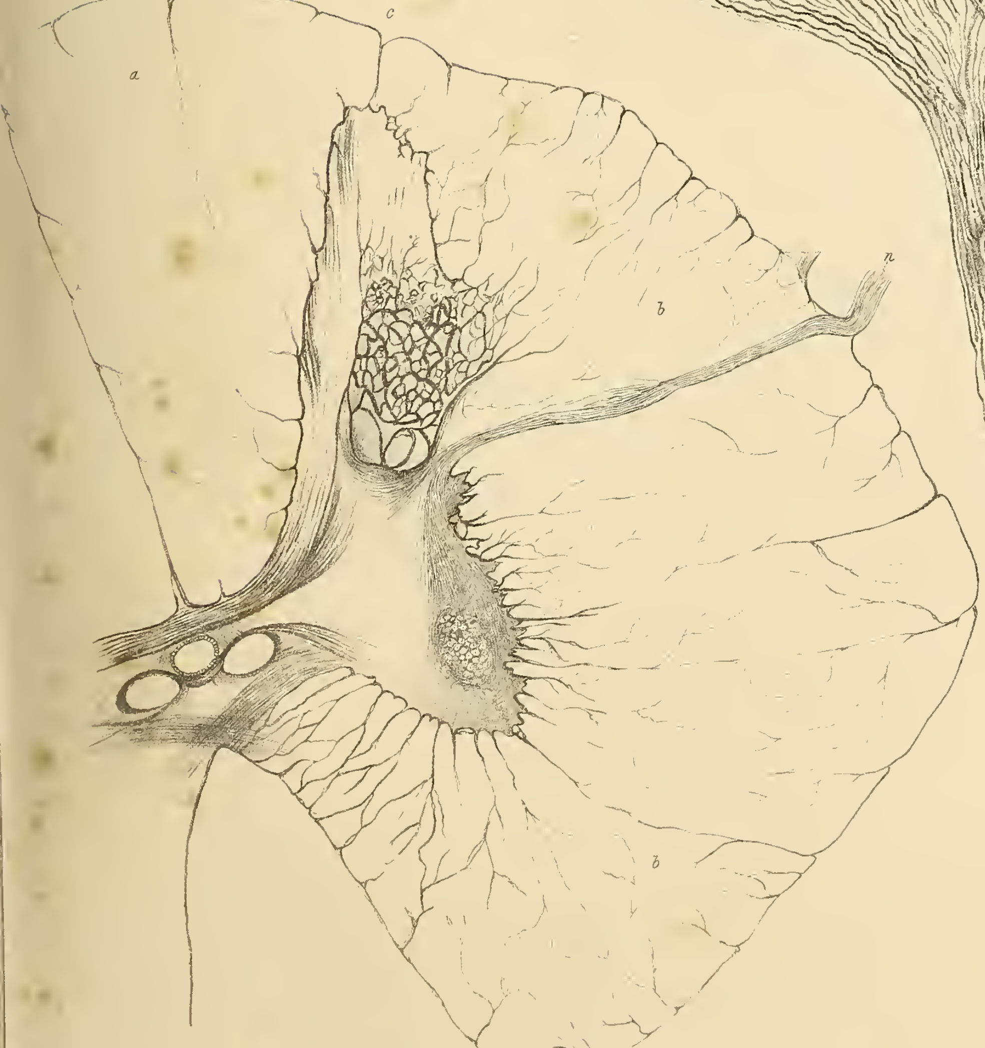

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PLATE XXIV.

Fig. 11. A similar section of one side through the middle of the cervical enlargement, between the roots of the nerves; *l′l′l′*, nerve-tubes and blood-vessels passing out from the grey substance; the bundles of nerves are seen breaking up amongst the clusters of nerve-vesicles; magnified 20 diameters.

Fig. 12. A section of the grey substance of one side, immediately below the first cervical nerves; magnified 20 diameters. *m*. Nucleus of the spinal-accessory nerve.

PLATE XXV.

Fig. 13. A section of the white and grey substance of one side through the lower part of the medulla oblongata; magnified 20 diameters. The spinal-accessory nerve, *n*, is seen entering the grey substance through the lateral column, and proceeding forwards to the vesicles of the anterior cornu.

Fig. 15. A group of caudate vesicles, traversed by the fibrils of the anterior roots of the nerves. From a section of one of the anterior cornua in the lumbar enlargement of the chord; prepared according to the second method, and magnified 220 diameters.

XXVII. *On the Meteorology of the Lake District of Cumberland and Westmoreland, including the Results of Experiments on the Fall of Rain at various heights, up to* 3166 *feet above the sea-level.—Fourth paper, for the year* 1850. *By* John Fletcher Miller, *F.R.S., F.R.A.S., Assoc. Inst. C.E. &c.*

Received February 21,—Read March 13, 1851.

Introductory Remarks.

In the month of December last I visited the Lake District, chiefly with the view of ascertaining approximately, the heights above the sea of some of the mountain gauges which I have hitherto been obliged to estimate. The heights of these stations were taken by means of an excellent aneroid barometer (previously compared with a standard), and a standard barometer read simultaneously, or nearly so, at the sea-level. By this method I found the height of Cockermouth above the sea to be 127 feet, Keswick 253 feet (Crosthwaite 258 feet), Bassenthwaite Lake and Lowdore (measured from Keswick) 214 and 224 feet respectively; Seathwaite (mean of two observations calculated from Lowdore) 368 feet; from Wastdale Head, 399 feet; and taken direct from the sea-level, 389 feet. I find the summit of Seatollar Common to be about 1590 feet, and the gauge 1388 feet above the sea, assuming the elevation of Seathwaite to be 368 feet; the gauge on Sprinkling Fell or the Stye, 948 feet, measured from Wastdale, and 936 feet by a simultaneous barometrical reading at the coast. Two distinct observations taken on the 16th and 17th of December, show the gauge near the top of Stye Head Pass to be 1443 and 1448 feet above the sea respectively, supposing the height of Wastdale Head village to be 247 feet. Mr. Otley states the summit of the Pass to be 1250 feet above the valley, or, taking Wastdale Head at 247 feet, 1497 feet above the sea; and an observation of Dr. Dalton's from the same base, gives 1506 feet, both of which correspond very nearly with my own results, as the gauge is somewhat *below* the highest part of the road leading over the Pass. I have hitherto stated the height of this station to be 1250 feet, but it appears I have misinterpreted my authority (Mr. Otley), whose calculation represents the height above the *valley*, not above the sea. The gauges on Brant Rigg and on Lingmell appear to be 924 and 1778 feet respectively above the sea. At the latter station, the barometer fell to 27·00 in., while in the valley it stood at 28·67 in., and at Whitehaven at 28·86 in. Temperature in the valley 48°; at 1778 feet, 32°·8, wet bulb 32°·2, heavy rain falling. I was prevented from ascending to any of the higher stations by the unfavourable state of the weather; indeed the barometrical observation at Brant Rigg, and also a second reading on Stye Head were taken at night, after having been confined to the valley the whole of the day by torrents of rain; I have consequently not had an opportunity of ascertaining the altitude of Sprinkling Tarn, but in 1812 Dr. DALTON states it to be 1860 feet; and another observation, either by DALTON or OTLEY, gives 1943 feet above the sea. I have therefore allowed the elevation of 1900 feet, previously given in my tables, to remain unaltered for the present. A complete and authentic table of the heights of our principal lakes and mountains is much wanted. Of the elevations given in the Guide Books to the Lake District, some are probably not far from the truth, but others are undoubtedly very erroneous; thus, Ennerdale Lake, by the Whitehaven Waterworks' Survey, proves to be 356 feet above the sea, instead of 246 feet, as stated in one of these treatises, showing an error or miscalculation of 110 feet. This is, no doubt, an extreme instance; but the altitudes of several of our lakes and mountains are yet unknown; and a careful measurement or remeasurement of the whole of them with accurate instruments and under favourable circumstances, is very desirable, as the results would be more or less interesting and valuable both to the meteorologist and the geologist, the botanist and the tourist.

TABLE I.—Synopsis of the Fall of Rain in the Lake District of Cumberland and Westmoreland, in the year 1850.

No.	I.	III.	IV.	V.			VI.	VII.	VIII.	IX.	X.	XI.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XX.	Prevailing winds.		
	Whitehaven.			Cockermouth, &c.											Westmoreland †.			Borrowdale.				
1850.	High Street, 90 feet above the sea.	St. James's Church Steeple, 78 feet above the street.	The Flosh, three miles south of Whitehaven.	The Town, 127 feet above the sea.	Tarn Bank*, 207 feet above the sea.	Broughton Moor, 410 feet above the sea.	Bassenthwaite Halls, 210 feet above the sea.	Keswick, 258 feet above the sea.	Vale of Gillerthwaite, Ennerdale, 396 feet above the sea.	Loweswater, 336 feet above the sea.	Foot of Crummock Lake, 260 feet above the sea.	Gatesgarth, 290 feet above the sea.	Eskdale Head.	Wastdale Head, 247 feet above the sea.	The How, Troutbeck, 300 ? feet above the sea.	Ambleside, 190 ? feet above the sea.	Langdale Head, 250 ? feet above the sea.	Seathwaite, 368 feet above the sea.	Stonethwaite, 330 feet above the sea,	At Crummock Lake, two observations daily.	At Seathwaite, one observation daily.	At the Coast, two observations daily.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.			
January......	2·995	2·797	3·63	4·14	3·23	3·56	3·10	2·914	4·89	4·130	4·49	4·13	5·68	7·26	4·744	5·20	7·07	7·34	5·20	E. var.	N.W. var.	S.W.
February ...	4·836	3·104	6·18	6·53	4·84	3·96	6·40	8·582	12·00	8·775	10·87	15·66	9·52	15·25	15·504	14·45	21·66	22·58	17·01	N.W. & S.W.	N.W.	S.W.
March	·969	·553	1·65	1·33	1·03	·59	1·45	1·268	4·13	2·365	3·31	3·38	3·59	3·55	1·624	1·73	3·04	4·13	3·42	Easterly.	E. & W.	Westerly.
April.........	3·113	2·304	4·08	2·46	2·79	2·07	3·30	4·760	7·14	5·255	8·01	10·34	8·25	9·34	8·523	6·64	11·51	15·62	9·63	S.E.	S.E. var.	S.W.
May	1·329	·823	1·37	2·08	1·60	1·50	2·26	2·721	3·00	2·935	4·27	6·20	3·45	4·78	3·377	2·91	5·46	7·14	5·89	S.W. var.	Westerly.	S.W.
June	2·012	1·233	2·63	4·17	2·38	2·40	3·74	3·910	6·30	6·000	5·40	5·79	4·69	5·97	4·845	3·99	6·76	6·83	4·43	S.W.	S.W.	S.W.
July	5·358	4·131	6·66	6·18	5·65	4·53	5·35	6·254	8·65	8·265	8·26	11·56	6·46	9·75	7·189	6·54	9·50	11·20	9·45	N.W.	S.E. & S.W.	N.W. var.
August	4·501	3·073	5·74	4·92	4·53	3·63	5·00	7·205	10·43	7·840	10·73	15·75	8·47	11·28	8·362	9·27	13·40	16·22	12·50	N.W.	N.W.	N.W.
September...	2·643	2·158	2·52	2·07	2·54	2·03	1·51	3·234	4·03	3·110	4·01	5·21	4·02	3·93	2·810	3·82	4·12	5·85	4·46	E. var.	E. var.	S.W.
October......	3·364	2·213	4·86	3·69	4·53	2·83	3·66	5·582	6·00	6·045	7·58	8·52	8·27	11·60	6·556	6·58	14·92	12·94	9·33	N.W.	N.W. & S.W.	N.W. var.
November...	6·258	4·152	8·13	7·44	4·84	4·75	7·24	8·966	12·34	9·545	12·72	15·45	12·16	17·82	9·798	13·26	20·55	22·60	16·94	S.W. & N.W.	S.W.	S.W.
December...	3·095	2·095	3·83	2·73	3·06	2·50	3·96	4·102	5·72	4·533	6·01	6·85	7·13	8·23	6·476	5·46	8·57	11·51	7·55	S.W.	S.W. & N.W.	S.W.
1850.	40·473	28·636	51·28	47·74	41·02	34·35	46·97	59·528	84·63	68·798	85·66	108·84	81·69	108·76	79·808	79·85	126·56	143·96	105·81	S.W. & N.W.	N.W. & S.W.	S.W.
1849.	38·999	28·210	45·13	38·39	38·71	31·82	40·00	48·80	76·41	55·28	70·21	97·09	71·22	107·22	75·420	65·32	107·83	125·47	94·27	S.W.	S.W.	S.W.
1848.	47·342	36·344	60·82	52·37	......	......	47·06	66·407	97·73	76·668	98·07	133·55	86·78	115·32	91·347	77·58	130·38	160·89	130·24	S.W.	S.W.	S.W.
1847.	42·921	30·713	47·80	42·55	......	......	44·45	58·286	80·13	66·296	82·32	106·25	74·93	96·34	78·004	......	112·95	129·24	106·21	W.	S.W.	S.W.
1846.	49·134	35·422	55·16	52·41	......	......	......	67·678	83·87	79·249	96·47	121·90	......	106·93	77·719	......	127·40	143·51		S.W.	S.W.	S.W.
1845.	49·207	33·489	53·00	46·93	......	......	......	62·202	76·88	69·542	87·48	124·13	......	108·55	76·305	......	136·00	151·87	......	S.W. var.	......	S.W. var.
1844.	36·723	27·862	39·31	......	......	......	......	40·629	54·62	49·829	61·46	......	......	80·01	51·986							
Mean of 7 years	43·514	31·525	50·35	46·73	39·86	33·08	44·62	57·467	79·18	66·523	83·09	108·84	78·65	103·30	75·798	74·25	123·52	142·49	109·13	S.W.	S.W.	S.W.

* Tarn Bank bears S.W. from Cockermouth, distant four miles; the Broughton Moor Station is three miles N.W. of Cockermouth, and 2¾ miles S.E. of Maryport.

† At Kendal, the fall in 1850 is 49·57 inches (average of twenty-eight years, 54·43 inches); at Selside, six miles from Kendal, 76·39 inches (average of three years, 73·87 inches); and at Bowness, near Windermere Lake, 64·28 inches.

TABLE II.—Wet Days.

1850.	Whitehaven.	The Flosh.	Cockermouth.	Tarn Bank, near Cockermouth.	Bassenthwaite Halls.	Keswick.	Loweswater Lake.	Crummock Lake.	Wastdale Head.	Troutbeck*.	Ambleside.	Langdale Head.	Seathwaite.	Stonethwaite.
January ...	12	15	9	12	11	13	12	12	16	9	13	13	12	12
February...	20	22	20	23	21	22	23	20	26	21	21	23	23	22
March......	10	10	9	11	9	11	9	12	15	7	5	12	12	9
April	18	17	18	20	18	20	21	21	24	20	21	20	21	21
May	15	15	14	18	14	16	14	14	21	16	14	14	19	14
June	10	10	15	15	12	12	14	12	19	12	11	13	16	14
July.........	13	15	18	18	19	19	14	17	17	14	11	15	15	13
August ...	22	24	23	17	21	23	19	20	24	16	17	22	24	18
September..	11	10	10	9	10	12	12	12	13	9	8	11	12	10
October ...	19	20	19	17	18	20	22	22	25	22	22	22	24	24
November..	19	23	23	14	22	23	20	24	26	21	22	24	24	23
December..	20	20	21	19	19	18	18	18	22	18	17	22	21	19
1850.	189	201	199	193	194	209	198	204	248	185	182	211	223	199
1849.	189	185	191	......	182	205	191	185	236	186	159	199	193	183
1848.	210	207	228	......	196	229	217	207	243	201	......	212	232	224
1847.	191	183	210	......	199	204	190	199	226	188	......	209	202	195
1846.	200	208	234	......	......	213	198	216	234	194	......	213	219	
1845.	193	175	212	......	......	195	195	202	211	180	......	......	211	

TABLE III.—Showing the Quantity of Rain received by the Mountain Gauges in eleven months, between the 1st of February and the 31st of December 1850.

No.	XXI.	XXI.²	XXII.	XXIII.	XXIV.	XXV.	XIV.	XIII.	XXVII.	XXVI.	XIX.
							The Valley.		Borrowdale.		
1850.	Sca Fell Pike, 3166 feet above the sea.	Lingmell, 1778 feet above the sea.	Great Gabel, 2925 feet above the sea.	Sprinkling Tarn, 1900? feet above the sea.	Stye Head, 1448 feet above the sea.	Brant Rigg, 924 feet above the sea.	To the west, Wastdale, 247 feet above the sea.	To the south-east, Eskdale, height unknown.	The Stye, 948 feet above the sea.	Seatollar Common, 1388 feet above the sea.	The Valley, Seathwaite, 368 feet above the sea.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
February†..	10·50	12·00	12·82	17·60	13·32	12·00	15·25	9·52	29·40	21·20	22·58
March......	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	3·55	3·59	5·06	4·27	4·13
April‡......	10·00	11·07	9·00	17·00	17·05	12·22	9·34	8·25	20·30	14·34	15·62
May	5·48	4·44	5·28	7·30	6·05	3·95	4·78	3·45	8·36	6·85	7·14
June	6·00	5·95	5·84	7·59	6·15	5·51	5·97	4·69	8·41	8·00	6·83
July.........	9·56	9·36	9·57	12·78	10·98	9·74	9·75	6·46	13·31	10·46	11·20
August ...	11·16	11·77	10·23	17·26	13·59	8·99	11·28	8·47	20·27	18·21	16·22
September..	3·53	4·60	3·41	5·86	5·76	4·80	3·93	4·02	9·91	5·78	5·85
October ...	Frozen.	9·70	10·96	13·18§	17·10	10·84	11·60	8·27	17·11	13·32	12·94
November..	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	17·82	12·16	28·06	24·15	22·60
December..	24·08‖	23·61	20·17	29·23	25·53	23·05	8·23	7·13	14·14	12·26	11·51
Inches......	80·31	92·50	87·28	127·80	115·53	91·10	101·50	76·01	174·33	138·84	136·62

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* At Kendal, 168; at Selside, six miles from Kendal, 193; and at Bowness, near Windermere Lake, 217 wet days.

† The month of January 1850 was included in the Tables for 1849, in consequence of the gauges being frozen up at the close of the latter year.

‡ April 30. This morning the summits of Gabel and Sca Fell were capped with snow ankle deep, and it froze keenly. The receivers were iced over at both stations, but not so strongly as to prevent the water being measured off.

§ In October, the normal proportion betwixt Stye Head and Sprinkling Tarn is inverted. On inquiry, I find the quantities as given in the Table are correct.

‖ The Sca Fell gauge was frozen on the last day of the year; the receiver was brought down to the valley and the ice melted. The funnel was filled up with snow, which accounts for the relatively small quantity of water received by this gauge during the last quarter. The fall of snow is very much greater on Sca Fell than on Gabel, although the difference in altitude is only 241 feet.

TABLE IV.—For the Summer Months.

No.	XXI.	XXI.²	XXII.	XXIII.	XXIV.	XXV.	XIV.	XIII.	XXVII.	XXVI.	XIX.
							The Valley.		Borrowdale.		
1850.	Sca Fell Pike, 3166 feet above the sea.	Lingmell, 1778 feet above the sea.	Great Gabel, 2925 feet above the sea.	Sprinkling Tarn, 1900 feet above the sea.	Stye Head, 1448 feet above the sea.	Brant Rigg, 924 feet above the sea.	To the West, Wastdale, 247 feet above the sea.	To the South-east, Eskdale, height unknown.	The Stye, 948 feet above the sea.	Seatollar Common, 1338 feet above the sea.	The Valley, Seathwaite, 368 feet above the sea.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
May	5·48	4·44	5·28	7·30	6·05	3·95	4·78	3·45	8·36	6·85	7·14
June	6·00	5·95	5·84	7·59	6·15	5·51	5·97	4·69	8·41	8·00	6·83
July	9·56	9·36	9·57	12·78	10·98	9·74	9·75	6·46	13·31	10·46	11·20
August ...	11·16	11·77	10·23	17·26	13·59	8·99	11·28	8·47	20·27	18·21	16·22
September..	3·53	4·60	3·41	5·86	5·76	4·80	3·93	4·02	9·91	5·78	5·85
October ...	8·64	9·70	10·96	13·18	17·10	10·84	11·60	8·27	17·11	13·32	12·91
Inches......	44·37	45·82	45·29	63·97	59·63	43·83	47·31	35·36	77·37	62·62	60·18

TABLE V.—For the Winter Months.

1850.	Sca Fell Pike.	Lingmell.	Great Gabel.	Sprinkling Tarn.	Stye Head.	Brant Rigg.	The Valley.		Borrowdale.		
							To the West, Wastdale.	To the South-east, Eskdale.	Seatollar Common.	On the Stye.	The Valley, Seathwaite.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
February...	10·50	12·00	12·82	17·60	13·32	12·00	15·25	9·52	21·20	29·40	22·58
March ...	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	Frozen.	3·55	3·59	4·27	5·06	4·13
April	10·00	11·07	9·00	17·00	17·05	12·22	9·34	8·25	14·34	20·30	15·62
November..	Frozen.	Frozen.	Frozen.	Frozen	Frozen.	Frozen.	17·82	12·16	24·15	28·06	22·60
December..	15·44	23·61	20·17	29·23	25·53	23·05	8·23	7·13	12·26	14·14	11·51
Inches......	35·94	46·68	41·99	63·83	55·90	47·27	54·19	40·65	76·22	96·96	76·44

TABLE VI.—Temperature at Seathwaite, Borrowdale, 368 feet above the sea-level.

1850.	Absolute		Mean of max.	Mean of min.	Approximate mean Temperature.	Mean at 9 A.M.	On Grass.				Prevailing winds.
							Absolute min.	Mean.	Radiation.		
	Max.	Min.							Max.	Mean.	
January	48°	19°	36°88	29°82	33°35	32°95	11°	23°42	9°8	6°40	N.W. var.
February ...	49·5	29	45·48	38·90	42·14	41·14	19	31·87	16	7·03	N.W.
March	53	21	44·53	34·87	39·70	38·00	18	29·41	10·5	5·46	E. and W.
April	56	32	50·51	40·91	45·71	45·12	27	35·31	15	5·60	S.E. var.
May	68·5	30	54·98	43·80	49·39	48·29	19	35·58	14	8·22	Westerly.
June	73·3	42	61·99	52·53	57·26	56·66	37	46·65	13	5·88	S.W.
July	76	43	65·51	54·02	59·76	59·26	34	47·61	14	6·41	S.E. and S.W.
August	72	39·5	61·06	50·71	55·88	55·13	30·5	44·42	12·5	6·29	N.W.
September ...	61	39	57·46	47·50	52·48	51·18	31	42·60	15	4·91	E. var.
October	55	27	47·26	38·77	43·01	42·60	22	32·86	9·5	4·64	N.W. and S.W.
November ...	52	20·5	43·53	39·03	41·28	41·44	...†	......	......	......	S.W.
December ...	51	22	43·47	36·00	39·73	40·48	...†	......	......	......	S.W. and N.W.
1850.	59·6	30·3	51·05	42·23	46·64	46·02	......	......	......	......	N.W. and S.W.
1849.	61·8	31·1	51·78	41·81	46·79	46·18	21·5	35·67	12·4	6·23	S.W.
1848*.	62·4	30·5	52·15	42·06	47·10	46·76	20·5	35·18	12·9	6·91	S.W.
1847.	62·7	29·9	52·89	42·04	47·46	47·21					
1846.	63·0	33	53·77	44·05	48·91	48·13					

* On the 1st of May, 1848, the thermometers were removed from the garden wall (where they were affected by solar radiation) to the gable end of a building facing the north where the sun never touches them, but the change of position does not appear to have materially affected the *mean* of the maximum readings.

† The results of the thermometer on grass for November and December, are omitted for the reason assigned in the remarks.

Note.—The mercurial thermometer got deranged in August, and a duplicate sent to supply its place was also found to be separated in the column on its arrival at Seathwaite, and consequently useless. Considerable delay took place before the instruments were adjusted, and the registrar did not receive them again till the middle of December. From about the middle of August till the 17th of December, the maximum was obtained by frequent examination of the spirit thermometer in the course of the day; the mean of the maximum for 1850 is in consequence about 1°·5 too low.

The mercurial thermometer, prior to its getting out of order, was considered to be nearly free from index error, and the night thermometer has been compared with it throughout the scale, and reduced to the mercurial as a standard.

Table VII.

Temperature at Whitehaven on the West Coast, 90 feet above the sea-level, and seventeen miles distant in a direct line, bearing W.N.W. from the hamlet of Seathwaite, Borrowdale.

1850.	Absolute		Mean of Maximum.	Mean of Minimum.	Approximate mean Temperature.	Mean. at 9 A.M.	Naked Thermometers on Grassplot*.							
	Maximum.	Minimum.					Absolute Minimum.		Mean.		Radiation.			
											Maximum.		Mean.	
							On Grass.	On Wool on Grass.	On Grass.	On Wool on Grass.	On Grass.	On Wool on Grass.	On Grass.	On Wool on Grass.
January	48°·5	21°·5	37°·62	30°·85	34°·241	33°·87	12°	8°	25°·94	22°·74	11°·8	15°·5	4°·91	8°·11
February.........	52·5	33	46·00	40·00	43·000	42·55	29·7	26	37·00	34·91	8·3	12·0	3·00	5·09
March............	52·5	25	45·89	37·30	41·590	40 59	16·2	8	32·35	28·65	10	16	4·95	8·65
April	63	35	54·47	42·83	48·650	49·01	26	19·5	37·73	35·04	10·5	16	5·10	7·79
May	70	32·5	57·35	43·75	50·550	52·00	26	18·5	37·86	34·03	13·5	17	5·89	9·72
June	78·5	44·5	65·55	53·46	59·505	60·53	41·5	37	48·33	45·62	12·5	15·5	5·13	7·84
July	84	47	68·14	55·53	61·835	62·93	42	33·5	51·36	47·88	9	14	4·17	7·65
August	72	42	64·92	52·51	58·715	59·45	33·5	30	46·84	44·10	12	15	5·67	8·41
September	66	39·5	61·83	48·50	55·165	55·55	28	24	42·71	40·01	13	18	5·79	8·49
October	61	32	53·30	42·38	47·846	47·43	26	20·5	37·86	35·16	9	14	4·52	7·22
November	57	24·5	48·90	42·50	45·700	45·38	16	13	37·25	35·74	8·5	12·5	5·25	6·76
December	52·5	25·5	45·61	39·21	42·412	41·97	15·5	12	33·35	31·33	11	17	5·86	7·88
1850.	63·1	33 5	54·13	44·07	49·104	49·28	26·0	20·8	39·04	36·26	10·7	15·2	5·02	7·80
1849.	62·3	33·7	53·24	44·15	48·696		23·5	18·8	38·04	35·05	14·0	18·4	6·11	9·09
1848.	62·9	32·6	53·77	43·79	48·785			20·2		35·73		15·9		8·06
1847.	62·3	33·7	53·85	43·50	48·679			20·5		35·95		15·1		7·45
1846.	64·8	36·1	55·95	45·75	50·858			23·1		38·30		14·6		7·45

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* The results of the thermometers exposed to the sky at Whitehaven and at Seathwaite, are not strictly comparable. At Seathwaite, the thermometer on grass is a common spirit thermometer on a boxwood scale. Naked thermometers were used for a year or two, but the observations were so frequently interrupted by breakage, that it was deemed preferable to employ a less fragile instrument.

Remarks.

The fall of rain throughout the Lake District in 1850, is slightly above the average of the six preceding years. At Seathwaite, the depth is 1·77 inch over the average of this period. The largest daily falls in 1850, at the three principal stations, are grouped as under:—

	Wastdale.	Langdale.	Seathwaite.
	days.	days.	days.
Between ½ an inch and 1 inch	38	39	39
Between 1 inch and 2 inches	29	37	34
Between 2 inches and 3 inches	5	6	13
Between 3 inches and 4 inches	2	2	6
Between 4 inches and 5 inches	...	1	...
Days in 1850 exceeding 0·5 inch in depth	74	85	92

Temperature.—At Seathwaite, the average mean temperature of the last five years is 47°·38; mean of maximum, 52°·32; mean of minimum, 42°·43. At Whitehaven, on the west coast, seventeen miles distant in a direct line, bearing W.N.W. from Seathwaite, the mean of the maximum for the same period is 54°·18; mean of minimum, 44°·25; average mean temperature, 49°·22.

The mean difference between the two places is, in the maximum, 1°·86; in the minimum, 1°·82, and in the mean 1°·84, the temperature at Whitehaven being higher than at Seathwaite by these quantities. The mean temperature at Whitehaven from eighteen years' observations is 49°; at Greenwich, the mean for seventy-eight years is 48°·3; and at Somerset House for sixty-nine years, 49°·5.

The radiation of heat from the earth's surface at night, as indicated by self-registering thermometers fully exposed to the sky on grass, appears on the whole to be greater in the mountain valleys than at the coast, and particularly in summer; but, occasionally in the winter months, the results are strangely and unaccountably anomalous. Thus, in November 1850, the mean amount or effect indicated was only 0°·90, and in December the mean reading of the thermometer on the grass was identical with that at 4 feet above the surface. At Whitehaven, the amount in those months was 5°·25 and 5°·86. Yet the same instrument (which has been in use at Seathwaite since 1846) in nearly all the other months of 1850, shows a greater extent of radiation than at Whitehaven. Results almost equally abnormal were presented in the winter of 1846 and 1847, and as such they were omitted from the Tables for that year*. I have examined the thermometer employed at Seathwaite for indicating the direct effect of terrestrial radiation; the column is perfect, and I am satisfied it has no material index error, and that it is correctly read off; moreover, it is exposed in the same place throughout the year. The cause of its occasional anomalous indications in the winter months must therefore be left unexplained for the present.

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[*] Philosophical Transactions, Part I. 1849, p. 85.

The Mountain Gauges.—The phenomena exhibited by the mountain gauges in the year 1850, do not seem to call for any particular comment, as the results are very generally in accordance with the deductions embodied in former papers which have appeared in the Transactions of the Royal Society; and at the present time I am more anxious to eliminate new facts and to accumulate a mass of accurate observations and well-digested results made and obtained both in normal and abnormal seasons and under various modifying circumstances, than to theorize upon or draw from them inferences or conclusions which extended experience may modify, contradict or destroy. The following Table shows the excess or deficiency per cent. of the principal mountain gauges over or under the quantity of rain received by the adjacent valley of Wastdale, both in the summer and winter months, in each year since the instruments were erected in 1846.

The positive sign signifies that the quantity is greater, and the negative sign that it is less than the fall in the valley in the same period.

Summer Months.

Year.	Sca Fell Pike, 3166 feet.	Lingmell, 1778 feet.	Great Gabel, 2928 feet.	Sprinkling Tarn, 1900 feet.	Stye Head, 1443 feet.	Brant Rigg, 924 feet.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
1846*.	−13·5	...	− 7·5	+ 29·5	+12·0	−10·3
1847*.	−13·5	...	− 7·5	+ 29·5	+12·0	−10·3
1848.	− 1·0	...	− 6·0	+ 41·5	+20·5	−14·0
1849.	− 6·5	− 8·0	− 7·0	+ 17·3	+ 9·0	−18·5
1850.	− 6·2	− 3·2	− 4·3	+ 35·3	+26·1	− 7·3
Algebraical Sums.	−40·7	−11·2	−32·3	+153·1	+79·6	−60·4
Algebraical Means.	− 8·1	− 5·6	− 6·4	+ 30·6	+15·9	−12·0

Winter Months.

Year.	Sca Fell Pike.	Lingmell.	Great Gabel.	Sprinkling Tarn.	Stye Head.	Brant Rigg.
	per cent.		per cent.	per cent.	per cent.	per cent.
1846*.	− 42·5	...	− 38·5	+11·3	+ 4·5	−15·2
1847*.	− 42·5	...	− 38·5	+11·3	+ 4·5	−15·2
1848.	Leaked.	...	− 42·5	+ 1·5	+ 0·5	−14·6
1849.	− 43·5	−28·8	− 40·5	− 3·2	−21·2	−27·8
1850.	− 33·7	−13·9	− 22·5	+17·8	+ 3·2	−12·8
Algebraical Sums.	−162·2	−42·7	−182·5	+38·7	− 8·5	−85·6
Algebraical Means.	− 40·5	−21·3	− 36·5	+ 7·7	− 1·7	−17·1

The remarkable deficiency in the per-centage of rain both in the summer and winter months of 1849, is accounted for by the abnormal and relatively excessive fall of rain in the Vale of Wastdale in that year, as explained in my last report on the meteorology of the Lake District. The *increase* in the per-centage in the winter months of 1850 is doubtless attributable to the fact of the deposition being almost entirely in the form of rain, the fall of snow on the mountains having been unusually small both in the early and latter months of the past year.

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* The per-centages in 1846 and 1847, show the mean of the two years, which were tabulated together.

The most interesting and important circumstance connected with the experiments in 1850, is the discovery of a mountain station which promises to yield nearly one-third more rain than the celebrated hamlet of Seathwaite in Borrowdale, hitherto, and with good reason, considered to be the wettest spot in Great Britain. The new station is about a mile and a half distant from Seathwaite in a south-westerly direction, and 580 feet above it, or 948 feet above the sea-level, at the extreme southern termination of the valley; it is on the shoulder of Sprinkling Fell or the Stye, about 100 yards south of the road leading over the Stye Pass to Wastdale.

The actual quantity of water measured on Sprinkling Fell in *eleven* months of 1850, is 174·33 inches; but the receiver was found running over on four different occasions, by which I calculate 5 or 6 inches at least must have been lost to the instrument; hence, if we add 5·67 inches for overflow, and 9·49 inches for the computed depth in January (7·34 inches at Seathwaite), the result is 189·49 inches for the fall on the Stye in 1850, with 143·96 inches at Seathwaite*.

The wettest year since the commencement of the experiments is 1848, when 160·89 inches fell at Seathwaite; and, computing the fall at the new station for that year in the same proportion which the two localities bear to each other in 1850, we have 211·62 inches for the depth of rain on the Stye in 1848. An inspection of the following Table, which exhibits the fall at the coast during the last eighteen years, will show that the period (1844–50) over which the Lake District gauges have been in operation, has been far from a wet one.

Fall of Rain at Whitehaven (seventeen miles distant in a direct line from Seathwaite) during the last Eighteen Years, from 1833 to 1850 inclusive.

Month.	1833.	1834.	1835.	1836.	1837.	1838.	1839.	1840.	1841.	1842.	1843.	1844.	1845.	1846.	1847.	1848.	1849.	1850.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
January ...	·712	9·169	4·643	4·133	2·824	1·785	4·576	4·586	3·674	3·429	4·875	4·119	4·541	4·604	1·873	3·745	5·683	2·995
February...	4·235	5·303	7·597	3·626	5·278	·943	2·768	4·376	1·536	2·657	·863	3·499	2·830	2·007	1·827	7·815	2·045	4·836
March......	2·928	2·560	5·751	5·742	1·209	4·474	6·229	·396	3·800	4·912	1·927	3·746	3·735	4·460	1·370	4·588	·837	·969
April	2·346	1·404	1·367	2·939	1·789	2·355	1·463	·580	3·803	·551	6·046	2·658	2·587	2·848	2·560	·495	1·488	3·113
May.........	2·257	2·483	3·964	·010	1·148	3·238	·843	3·781	2·955	2·293	2·016	·262	1·480	2·317	3·428	1·798	3·037	1·329
June	6·783	4·682	1·601	6·642	3·647	7·125	4·063	5·893	4·512	1·861	4·497	3·878	4·099	2·311	2·912	3·867	1·224	2·012
July	4·384	5·065	5·451	7·146	7·245	4·893	5·681	8·138	4·569	3·782	6·104	4·183	2·900	9·061	·776	3·630	5·478	5·358
August ...	2·090	4·755	1·813	5·886	2·157	5·148	5·655	6·175	7·879	1·813	4·875	1·999	6·995	4·066	4·496	5·054	3·771	4·501
September.	2·339	4·281	6·507	6·399	3·305	3·289	6·714	5·754	5·670	2·871	·390	5·809	3·653	2·857	3·738	2·266	2·814	2·643
October ...	4·240	3·937	6·217	4·049	5·832	4·574	4·209	2·452	8·344	2·388	6·748	4·335	6·744	7·982	5·407	5·772	5·252	3·364
November.	7·094	2·749	4·996	6·150	4·620	4·481	4·048	4·420	3·955	3·702	5·569	1·926	4·022	4·671	7·937	3·507	4·974	6·258
December.	9·048	3·315	4·228	6·253	6·278	1·641	2·787	·893	5·276	4·434	2·296	·309	5·621	1·950	6·597	4·805	2·396	3·095
Total	48·456	49·703	54·135	58·975	45·332	43·946	48·976	47·444	55·973	34·693	46·206	36·723	49·207	49·134	42·921	47·342	38·999	40·473
Wet Days.	203	200	215	230	189	167	198	210	220	167	210	172	193	200	191	211	190	190
Average number of wet days, 197.																		

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* A new and capacious gauge was placed on the Stye early in January of the present year (1851).

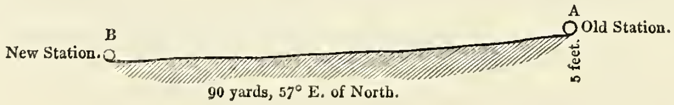
At Whitehaven, the average annual fall from 1844 to 1850 inclusive, is 43·543 inches; but in the eleven years preceding 1844, the average is 48·53 inches; and the average of the last eighteen years, from 1833 to 1850 inclusive, is 46·58 inches.

And if we analyse the period of seven years comprehended between 1844 and 1850, we find that only three of those years have exceeded the average; while of the remaining four, one year is characterized by drought, and the other three by unusual dryness. Even in the year 1848, when 161 inches fell at Seathwaite, the depth at Whitehaven was only 47·34 inches, or $\frac{3}{4}$ths of an inch above the average of eighteen years; whilst in 1835, the fall was 54·13 inches; in 1836, 58·97 inches; and in 1841, 55·97 inches.

It is not pretended that the gradation in quantity between Seathwaite and Whitehaven in any particular year will be the same in other single years, or that the differential mean of one term of years will correspond precisely with that of other terms of equal length, although I conceive that the proportion found to obtain for a group of ten consecutive years, will never be very widely departed from in future decennial periods; but we may, at least, fairly assume that a wet or a dry season at either station will bear a similar character at the other; and sufficient evidence has been adduced to show that the mean annual fall of rain in the Lake District has yet to be determined, by the incorporation of a future term of wet years with the comparatively dry period already on record. And this remark applies with still greater force to the maximum fall, as, judging from the records kept at the coast during eighteen years, no one of the last seven, during which the Lake District gauges have been in action, has any pretension to a character for excessive wetness.

Hence, the maximum annual depth in the mountain district of Cumberland may far exceed the computed fall of 211 inches at the Stye in 1848, enormous and almost incredible as is the quantity for a climate situated in the heart of the temperate zone. I may observe that the fall of rain at the coast in one year is rigidly comparable with any other year; the gauge having been in the same spot, or at least within a few feet of it, from the year 1832 up to the present time. Moreover, the same gauge and the same glass metre (graduated to the $\frac{1}{1000}$th part of an inch) have been used from the first; and the rain has been read off daily throughout the period.

In my paper printed in the Philosophical Transactions for 1848 (Part II.), allusion was made to the difference in the receipts of rain gauges within 100 yards of each other, when placed near the head of a valley. A still more remarkable instance is presented in the past year, but in this case the gauge is considerably elevated *above* the valley. On the 31st of August 1849, the gauge on Seatollar Common, 1338 feet above the sea, was removed 90 yards to the south-westward, nearly in a direct line, the difference in height between the old and new station being only 5 feet.



Gauge removed from A to B.

Below, are given the receipts of this gauge for the last five years, by which it will be seen that on the average of the three years ending with 1849, it has received 23·4 per cent. *less* than the valley; but in 1850, with the slight alteration in position just described, it has obtained 1·6 per cent. *more* rain than the valley, showing an annual increase of 25 per cent. consequent on the removal of the instrument 90 yards in linear distance, and a diminution of 5 feet in its height above the valley.

Year.	Seathwaite, 368 feet above the sea.	Seatollar Common, 1388 feet above the sea.	Deficiency per cent. at Seatollar Common.
	in.	in.	in.
1847.	129·24	104·55	−18·5
1848.	160·89	123·68	−23·1
1849.	125·47	108·97	
1849 to Aug. 31.	78·95	56·34	−28·7
1850.	143·96	146·18	+ 1·6

The records of the self-registering minimum thermometer on Sca Fell, in 1850, are as under:—

January and February, 31° below zero; March, 10° below zero; April, 10° below zero; May, 14°; June, 22°; July, observation lost; August, 9°; September, 7°; October, 7°; November and December, 15° below zero.

In the valley, the minima at 4 feet from the ground were,—in January, 19°; February, 29°; March, 21°; April, 32°; May, 30°; June, 42°; July, 43°; August, 39°·5; September, 39°; October, 27°; November, 20°·5; and December, 22°.

I have recently planted a minimum thermometer on the Gabel, and also one near Sprinkling Tarn, at the respective heights above the sea of 2928 and 1900 feet, and hope, in future, to obtain regular monthly readings at all the three stations.

The Observatory, Whitehaven,
February 6, 1851.

Erratum in Philosophical Transactions, Part I. *for* 1851.

Page 147, second line from top, *for* " severe *nights* " *read* " severe *droughts*."

XXVIII. *On the Annual Variation of the Magnetic Declination, at different periods of the Day. By Lieut.-Col.* Edward Sabine, *R.A., V.P. and Treas. of the Royal Society.*

Received April 30,—Read May 22, 1851; Revised October 1851.

THE interest which papers recently communicated to the Royal Society have excited in regard to the physical explanation of the Annual and Diurnal Variations of Terrestrial Magnetism, makes it extremely desirable that the facts which are to be explained should in the first instance be clearly and fully comprehended; and that for this purpose, the different classes of facts, which undergo much additional complication by being viewed together, should be distinguished apart, and that each class should be presented separately, combining at the same time, as far as circumstances may permit, facts of the same class obtained from different parts of the globe.

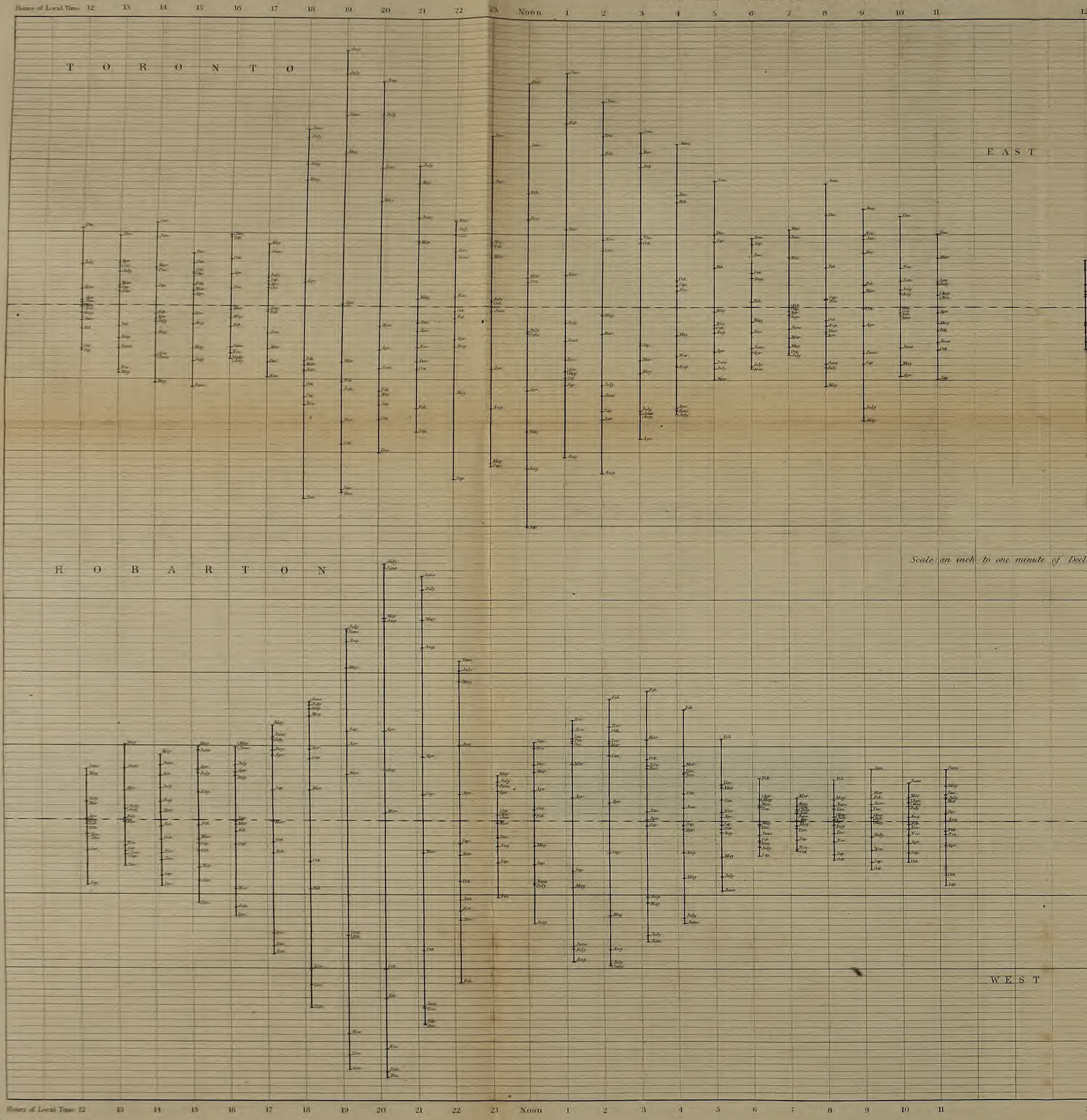
Under this impression I have deemed that an acceptable service might be rendered, by arranging in a small compass and presenting together the Annual Variations which the Magnetic Declination undergoes at every hour of the day at the four Colonial Observatories established by the British Government at Toronto, Hobarton, the Cape of Good Hope and St. Helena;—stations selected, it may be remembered, with the express view (amongst others) of affording, as far as any four stations of equally convenient access might be expected to do, the means of generalizing the facts of the Annual and Diurnal Variations in different quarters of the globe. I have attempted to accomplish this object by a graphical representation (Plate XXVI.), in which the Annual Variation at every hour is shown by vertical lines varying in length according to the amount of the range of the Annual Variation at each hour; each line having also small cross lines marking the mean positions of the several months in the annual range. The scale is the same for all the stations, being one inch to one minute of declination. The declination is that of the north end of the magnet at all the stations; the upper end of the line is always the eastern extremity, and the lower end the western extremity, of the annual range. The broken horizontal line which crosses all the verticals at each station, marks for each of the observation hours the mean declination in the year at that particular hour, obtained by adding together the daily observations of the declination at that hour, and dividing the sum by the number of days of observation in the year. This line is consequently not a line of uniform declination-value throughout, because the mean declination varies at different hours, by quantities which constitute the mean *Diurnal* Variation: but it is the line, or curve as it is sometimes called, of mean Diurnal Variation projected as a straight line, for the purpose of viewing the phenomena of the Annual Variation at each hour, irrespective of the Diurnal Variation, or the changes which the *mean* declination undergoes at different hours. The hours are those of mean solar time at each station, the day commencing at noon, and being reckoned through the twenty-four hours; noon is therefore $=0^h$. The fractional minutes are occasioned by the observations having been made at the exact hours of *Göttingen* time, which differ more or less at each station from exact hours of local time.

The Annual Variations represented in Plate XXVI. were obtained at Toronto from three years of observation, viz. 1845, 1846 and 1847; at Hobarton from five years, viz. July 2, 1843 to July 1, 1848; at the Cape of Good Hope from five years, viz. July 2, 1841 to July 1, 1846; and at St. Helena from three years, viz. from July 2, 1844 to July 1, 1847. The secular change at the several stations during the years of observation has been eliminated; but what are frequently called the "irregular disturbances," are retained, as all observations are taken into the account. At Hobarton, the Cape of Good Hope and St. Helena, the Annual Variation is probably very little affected by the disturbances referred to; but it may be otherwise at Toronto, where they are larger, and especially influential during the hours of the night when the regular range of the Annual Variation is small. It is not probable, however, that the annual range during the hours of the *day* is materially affected by the disturbances, even at Toronto. The absolute values of the magnetic elements at the respective stations were nearly as follows in the mean of the years in which the observations were made:—

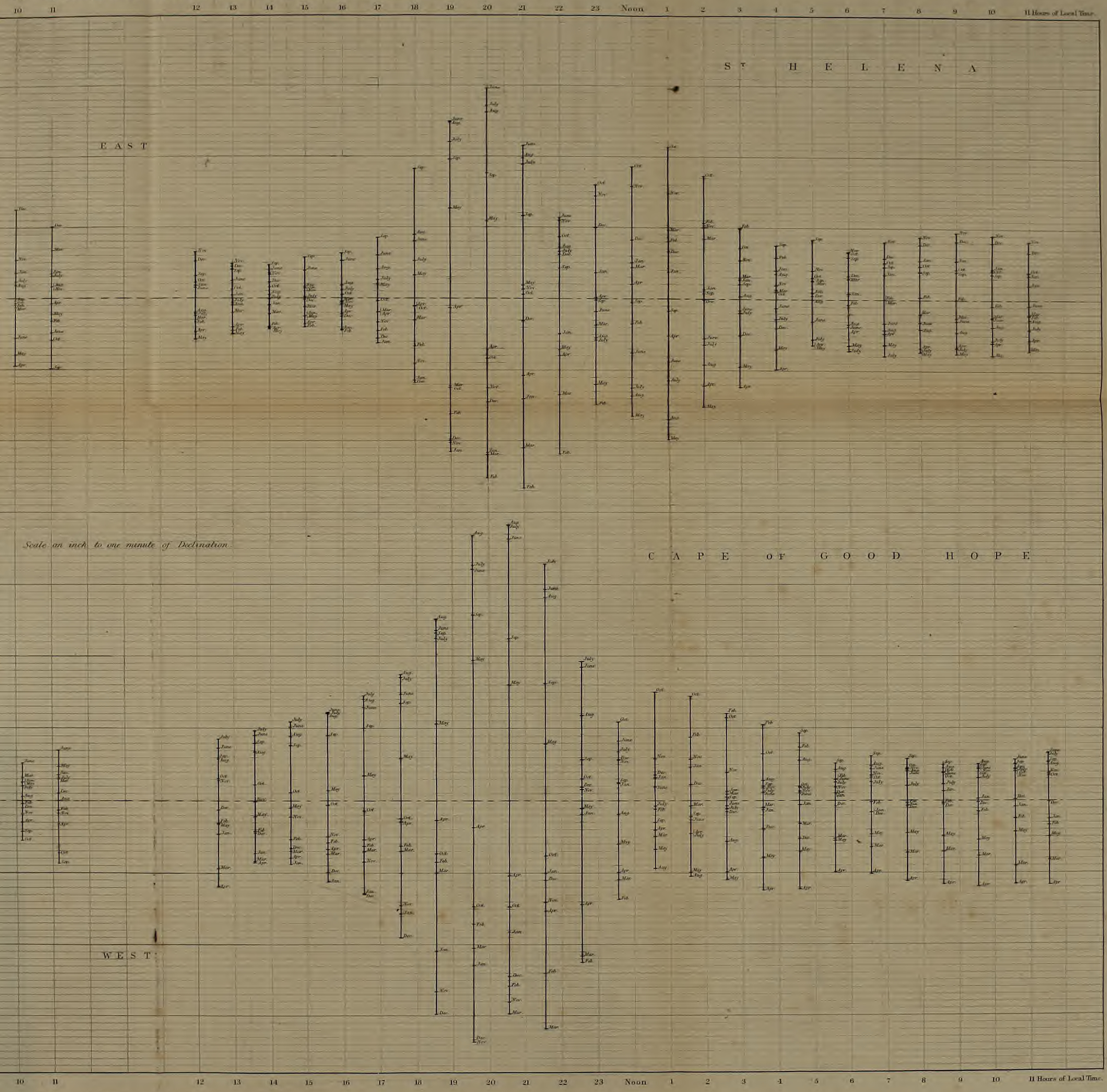
	Toronto.	Hobarton.	Cape of Good Hope.	St. Helena.
Declination	1° 33′ W.	9° 57′ E.	29° 07′ W.	23° 51′ W.
Inclination	75° 15′	−70° 34′	−53° 25′	−22° 07′
Total Force	13·90	13·56	7·48	6·01
Horizontal Force	3·54	4·51	4·46	5·57
Vertical Force	13·45	12·78	6·01	2·26

As the mode in which the subject of the Annual Variation is treated in this communication is I believe in some respects new, it has been suggested to me, since this paper was presented to the Society, that a fuller description than is given in the preceding paragraphs, of the process by which the graphical representation in Plate XXVI. is derived from the actual observations, may be desirable. I have therefore subjoined in Plate XXVII. a graphical representation for two of the stations, Toronto and Hobarton, of the direct and immediate results of the observations themselves, exhibiting according to their absolute declination-values the mean declination in each of the twelve months, at each of the twenty-four hours, of a *mean* year. The observations thus represented are, as before stated, at Toronto, three years of hourly observation, from January 1, 1845 to December 31, 1847 inclusive; and at Hobarton five years of hourly observation, from July 2, 1843 to July 1, 1848 inclusive. The *mean* or middle year at Toronto is therefore from January 1 to

ANNUAL VARIATION of the MAGNETIC DEC



Drawn by Corp.l W.J. Murphy, Royal Artiller the MAGNETIC DECLINATION at the different hours.



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RANGE OF THE MAGNETIC DECLINATION IN A MEAN OR TYPICAL YEAR.

Fig. 1. HOBARTON: year commencing with July.

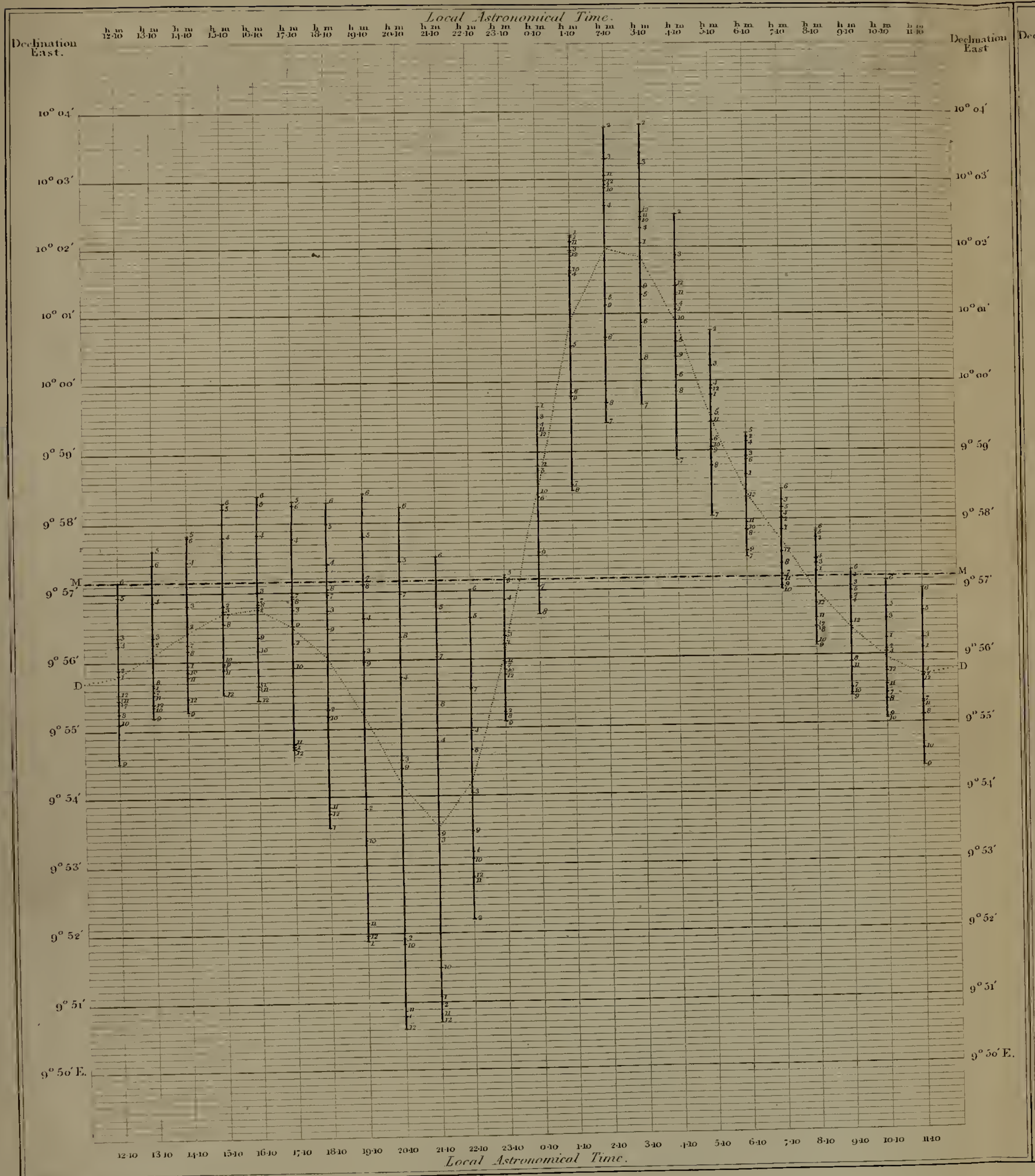
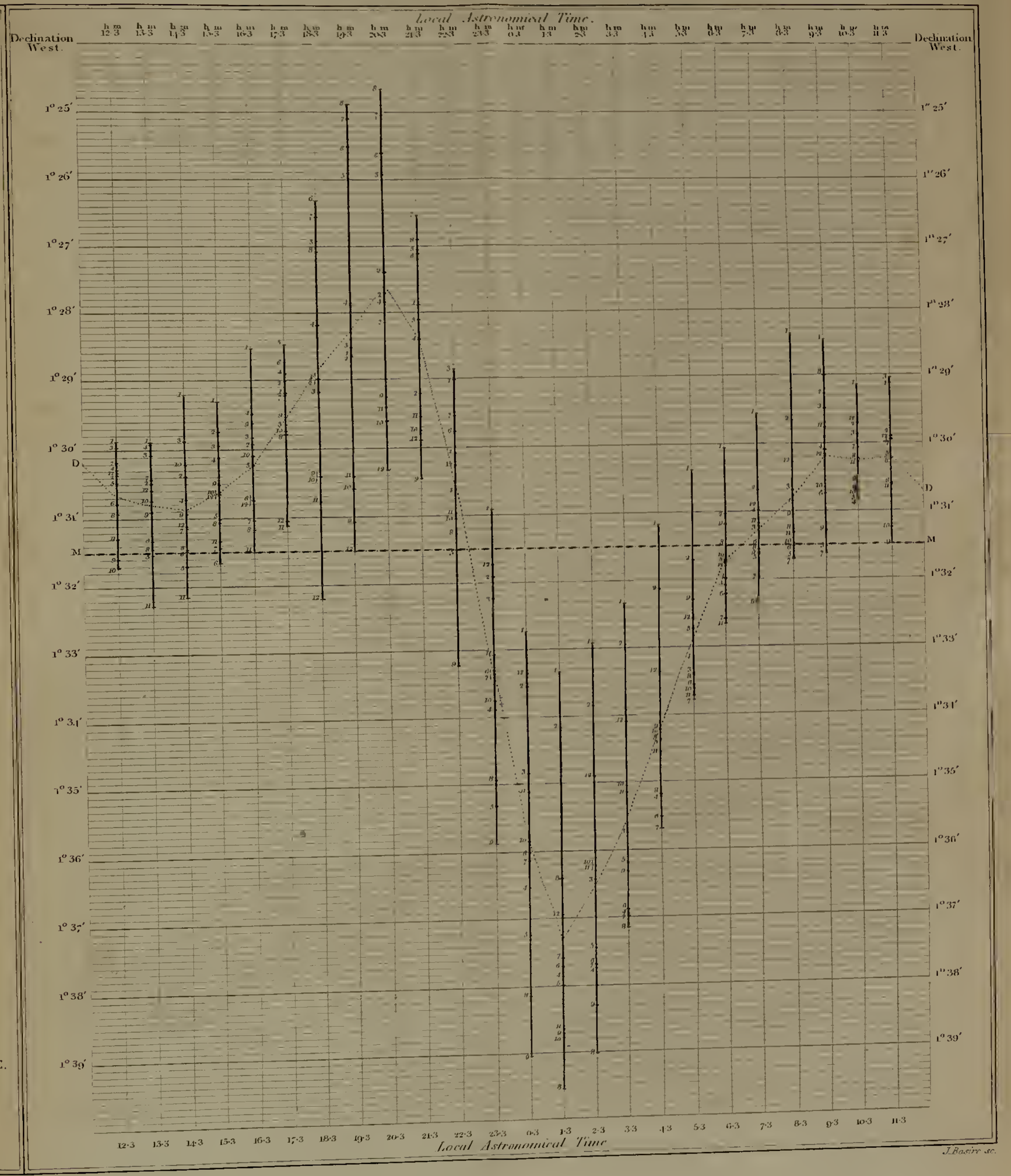


Fig. 2. TORONTO: year commencing with January.



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December 31, 1846; and the mean or middle year at Hobarton is from July 2, 1845 to July 1, 1846; the mean of the results in the same month and at the same hour in each year of the series (three years in the one case, and five years in the other) being taken as the declination-values corresponding to the mean year; which may thus be regarded as a type of the actual changes taking place in the declination in the course of a single year, at the period when the observations were made; but with the advantage that the various declination-values in the mean or typical year are derived in the one case from three, and in the other case from five years of continuous and intercomparable observations, instead of from one.

The dark vertical lines in Plate XXVII. exhibit the actual annual *range* of the declination at each of the observation hours. The figures on the left of the lines (on the left in the Toronto figure, and accidentally placed on the right of the lines in the Hobarton figure) show the positions in the annual range at each hour of the mean declination in the different months as derived from observations at that hour only; the months being distinguished by numbers, according to their order of succession, from 1 to 12, commencing with January. The broken line MM shows the *mean* declination of the *whole year*, viz. the mean declination of all the months and all the hours. The dotted line DD represents the mean *diurnal* variation in the year, or the mean variation of the declination at the different hours of the day and night: it is drawn through and connects the points of mean declination in the year at each of the hours respectively. The scale of declination-value in this Plate is reduced for convenience to half the dimensions of that of Plate XXVI.; in Plate XXVII. an inch is the equivalent of two minutes of declination, and in Plate XXVI. of one minute. The declination in both plates is that of the north end of the magnet, or that end which in the middle latitudes points towards the geographical north.

On an intercomparison of the observations represented in their mean monthly values at each hour in Plate XXVII., it is at once obvious that they are affected by three distinct and easily distinguishable variations, two of which are periodical, and one is secular. 1°. If the mean declination of the year at the different hours of the day and night had an uniform value, the line DD would be a straight line, and there would be no mean Diurnal Variation, or variation whose period is a *day*:—but DD is very far from being a straight line. 2°. If the mean declination at any particular hour of the day were of uniform value in all months of the year, the dark vertical line corresponding to that hour would be reduced to a point instead of a line, and there would be no Annual Variation, or variation whose period is a *year*, at that hour:—but the dark vertical lines are very far from being points at any hour of the day or night. 3°. If, on comparing the mean declination observed in any particular month and at any particular hour in one year with the mean declination in the same month and hour in preceding or succeeding years, the values were found uniform, or presenting at most such differences only as might reasonably be ascribed to observation errors, or to what are usually called magnetic disturbances, we might infer that the line

MM had a constant value at the station to which the figure in the Plate referred, and would apply to any other year as well as to the one in which it represents the "sum of all the observations in the year divided by their number." This, however, is not the case: the line MM prolonged into other years would not be found to correspond with the mean declination in adjoining years, or in any other year than the one represented. Both at Toronto and at Hobarton the line MM would have a less westerly declination-value in years preceding, and a greater westerly declination-value in years succeeding those represented in the Plate. This Variation, since the observatories have been established, has at each station been progressive from year to year; its period, if it has a period, is unknown; it has therefore been called "secular," to distinguish it from those variations which have known periods. Its value for particular years (as for example, for the three years at Toronto, and the five years at Hobarton, which are under present notice) may be satisfactorily determined by comparing the mean declination of one year with that of succeeding years, or of particular portions of the year with that of the same portions of succeeding years. At the Colonial Observatories it has been obtained by intercomparison in different years of the mean declinations corresponding to *fortnightly* periods; and the small amount of the probable errors of these determinations shows their satisfactory character. The amount of the secular variation is comparatively small at Toronto, Hobarton and the Cape of Good Hope; but it is large at St. Helena, being an annual increase of nearly eight minutes of west declination. This large amount at St. Helena has proved, however, in one respect, an advantage, by the opportunity it has afforded of examining the character of the progression according to which the secular change takes place, and of ascertaining by the concurrent evidence of several years, that the progression is *equable and uniform in all parts of the year.*

The mean secular change during the years represented in Plate XXVII. being thus known, the mean declinations of each of the months at each of the observation-hours have received a correction, previous to their insertion in Plate XXVI., for the purpose of eliminating the influence of secular change on their actual positions in the annual range. This correction is in each case the proportional part of the secular change due to the interval of time occurring between the month in question and the middle period of the year. At Toronto, Hobarton and the Cape, the correction is small and little significant, even in the months most distant from the middle of the year; and the Annual *Variation* is consequently very little different at these stations from the annual *range,* either in magnitude or in the relative position of the several months. But it is otherwise at St. Helena, where the secular change is large, and its elimination therefore is indispensable, even to an approximate knowledge of the phenomena of the Annual Variation. Happily at St. Helena the hypothesis of an uniform and equable distribution of the secular change throughout the year, upon which the elimination is based, has been shown by the series of fortnightly mean declinations continued for several years, to be a correct representation of the facts of nature.

For the mean Diurnal Variation, it is manifestly indifferent whether the secular change be eliminated or not; the line DD retains in either case its position and form unchanged, for the sum of the monthly corrections for secular change in every case =0. If, therefore, the Annual *Variations* were substituted for the annual *ranges* in the dark vertical lines in Plate XXVII., we have reason to believe that a correct representation would be given of what would be the facts of the Annual and Diurnal Variations if no secular change whatsoever existed; or if a secular change were to take place (as has recently been the case in Britain) in the opposite direction to that which previously prevailed, and were eliminated by the same process.

But when the vertical lines of Annual Variation are thus placed on the Diurnal Variation, projected as in Plate XXVII. according to its mean declination-value, the complexity occasioned by the two phenomena being viewed together is considerable, and is greatly increased when, as in Plate XXVI., four different stations are exhibited on the same plate, for the special purpose of examining and comparing one class of the phenomena only, (those of the Annual Variation,) as presented at different stations. To facilitate this examination and comparison, the curve, if such it may be called, of Diurnal Variation, has been projected in Plate XXVI. as a straight horizontal line; and in that Plate consequently the Annual Variations at the several observation hours may be viewed independently of Diurnal Variation, as well as of Secular Change.

On directing our attention to this Plate, it is perceived at the first glance, that the range of variation at all the stations is considerably greater during the hours of the day than during those of the night; and that there is a great similarity, though not a perfect identity, at all the stations, in the relative amount of the range at different hours. The amount does not progressively enlarge to a maximum at any obviously natural epoch,—such as, for example, at or about noon, when the sun's altitude is greatest, or at the early hours of the afternoon when the temperature is greatest,—but it will be distinctly seen that at all the stations the increase of the range is most rapid in the first or second hour after sunrise, and that its extent at the hours from 7 to 9 A.M. (19^h, 20^h and 21^h) is not exceeded at any subsequent hour at Hobarton, the Cape, and St. Helena; whilst at Toronto the great enlargement of the annual range takes place even earlier, the hours of 6, 7 and 8 A.M. being exceeded by none, though they are equalled by a second increase at noon and the two following hours. This second enlargement is also perceptible at the same hours, though not to the same extent, at Hobarton and St. Helena.

On examining the distribution of the months at the different hours, or their relative positions to each other in the several vertical lines, we may perceive that certain months, which are found congregated at the one extremity of the range during the early hours of the morning, undergo a transfer towards the opposite extremity at a subsequent period of the day; thus June, July and August, which, in respect to their positions in the range, may generally be grouped together, occupy usually one extremity of the range,—and November, December and January, which, from a similar reason, may also be grouped together, the other extremity,—in the early morning hours, and until from 8^h to 10^h A.M., about which time the two groups are respectively transferred, each towards the opposite quarter to that which it previously occupied. The period at which this transfer takes place is somewhat earlier at Toronto and St. Helena than at the Cape and Hobarton.

The comportment of the two equinoctial months, March and September, at the Cape of Good Hope and St. Helena, presents a contrast to that of the two solstitial groups which have been just described, and at the same time the two months are remarkably contrasted with each other. At the Cape, September is found exclusively on the *east* side of the mean line throughout the twenty-four hours, except at the observation hours of $0^h\ 34^m$ and $1^h\ 34^m$; and March as exclusively on the *west* side of the mean line throughout the twenty-four hours, excepting only at the observation hour of $2^h\ 34^m$. At St. Helena also September is found on the east side of the mean line at all hours of the twenty-four, except for one hour before and one hour after noon, when it is slightly on the west side; and March is found on the west side of the mean line with the exception of the hours from noon to 6 P.M. April participates with March in the peculiarity thus described both at the Cape and St. Helena. April is on the west side of the mean line at the Cape at all hours without exception, and at St. Helena at all hours with the exception of 11 A.M. and noon.

I abstain from dwelling on other particulars, fearing that, not possessing any clue towards an explanation of these remarkable phenomena, I may do harm rather than good by contributing to give an undue significance to what may not prove the most important features. I will only permit myself therefore to point out one or two practical considerations suggested by the facts now under notice.

1. Recent researches in meteorology have shown us, that when we confine our attention to the *mean* annual and *mean* diurnal values (of the temperature for example) in different parts of the globe, we derive but a small part of the instruction which the observation of nature is capable of affording. A similar remark applies with equal justice to the consideration of the variations of the magnetic elements. In the Annual Variation now before us, even a very cursory inspection is sufficient to show, that as the same months occupy positions on opposite sides of the mean line at different parts of the twenty-four hours, the *mean* Annual Variation, or that which is shown by the mean values in each month taken from *all* the observation hours, must be merely a residual quantity; and that consequently natural features must be more or less masked in deductions in which only mean values are brought into view. In fact, as has been shown in the published volumes of the observations at St. Helena and Hobarton, the *mean* annual variation at those stations is so small as to be scarcely sensible, more particularly at Hobarton, where its whole range amounts to not more than a small fraction of a minute of arc. But when we resolve these *mean* results into their respective constituents, viz. the Annual Variation *at each of the observation hours*, there is then at once disclosed to us an order of natural phenomena,

very far from inconsiderable in amount, systematic in general aspect, and apparently well deserving the attention of those who are occupied in the delightful and highly intellectual pursuit of tracing the agencies of nature.

2. We perceive in the variations of position of the several months in the annual range, the necessity of paying regard to the period of the year, as well as to the period of the day, at which observations have been made, which do not include long intervals, and from which nevertheless inferences are drawn in respect to secular change. Such observations, when not those of a fixed observatory, are usually made at some hour in the day-time, when it needs only a glance at the Plate to perceive that Annual as well as Diurnal variation-corrections are required, unless the month as well as the hour is the same in the earlier and later observations. A table of corrections for every hour of the day to the mean value in each month—corrections derived, as in the instances now before the Society, from a series of *strictly comparable* observations continued for several years—should be considered, not merely as a desirable, but as an almost indispensable provision, in countries where magnetic surveys are conducted with the degree of perfection of which they are now susceptible.

Woolwich, April 29, 1851; *revised October* 1851.

XXIX. *Investigations into the Structure and Development of the Scales and Bones of Fishes. By* W. C. Williamson, *Esq., Professor of Natural History, Anatomy and Physiology, in Owens College, Manchester.*

Communicated by Edwin Lankester, *M.D., F.R.S.*

Received June 20,—Read June 20, 1850.

In 1849, I had the honour of laying before the Royal Society a memoir on *Lepidogenesis,* in which I chiefly directed attention to the structure and growth of the dermal teeth and scales of Ganoid and Placoid fish*. Since the completion of that memoir, a large proportion of such leisure hours as could be snatched from the active duties of professional life, have been devoted to a still wider range of inquiry connected with the same subject. During the interval, I have made a great number of sections and other microscopic preparations of scales belonging to M. Agassiz's Cycloid and Ctenoid orders, as well as of the Ostraciont family of his Ganoid order: the results of the investigation having convinced me, that the structure of these organisms has hitherto been very imperfectly known, I am not surprised that their genesis and development have been involved in considerable obscurity.

A list of the various writers who have preceded me in this inquiry, was given in my last memoir. From this, it will be necessary to select two of the most modern observers, and to notice what their respective views are, in order that we may comprehend the bearing of my more recent observations upon those of my predecessors in the study: these are, M. Mandl and M. Agassiz.

M. Mandl has published an elaborate memoir on Cycloid and Ctenoid scales, in vol. ii. of the 'Annales des Sciences Naturelles,' in which he has developed his peculiar views respecting them. He has arrived at the conclusion, that Cycloid scales consist of *two* portions. "Nous avons ainsi acquis la preuve que la plupart des écailles sont composées de deux couches superposées; l'inférieure offre la structure des cartilages fibrineux, la supérieure, celle des cartilages à corpuscules; cette dernière est pourvue en outre de lignes, dont nous démontrons l'origine, par la fusion de cellules primitives; ces deux couches sont parcourues par des lignes longitudinales, qui appartiennent aux deux couches†." Observing certain radiating lines proceeding from the centre towards the circumference, especially in the anterior portion of the scale, he concluded that they were nutrient canals, which conducted the fluids from the skin to the centre of the scale, which he designates "le foyer," and which he regards as the centre of nutrition: "un lieu où le tissu se trouve dans son dévelopement." He then proceeds to explain the origin of his upper layer of "lignes cellulaires" as he terms them; meaning thereby, if I understand him aright, the concentric lines seen on the *surface* of the scale, and which he appears to imagine extend completely through its upper layer. "Nous avons par ces recherches acquis la certitude que ces lignes doivent leur origine à des cellules qui, primitivement, se forment dans la couche supérieure de l'écaille, placées sur une base; que peu-à-peu ces cellules se remplissent, s'allongent, et finissent par représenter des lignes plus ou moins larges, qui tout au plus, par un bord inégal, révèlent leur nature primitive*." M. Mandl then goes on to point out, very correctly, the structure of the inferior layer, which he describes as "composée de lamelles fibreuses, dont les fibres s'entrecoupent sous des angles réguliers, mais qui toutes suivent la même direction dans le même lamelle†." From these and other supposed facts, he draws the following general conclusion as to the way in which these scales have been formed—"Si nous voulons appliquer les résultats que nous avons obtenus dans l'étude de la structure intime des écailles, à l'explication de la manière dont elles se forment, nous verrons tout d'abord qu'il importe de bien distinguer la formation de la couche supérieure, et celle de la couche inférieure. La première, composée de cellules et de leurs bases avec le tissu qui contient les corpuscules, prend son dévelopement par des accroissements qui ont lieu dans la périphérie, autour des lignes cellulaires; au moyen, de pareils accroissements, ils forment, non-seulement plusieurs lignes cellulaires, mais les canaux longitudinaux eux-mêmes se trouvent allongés. Il est très probable que ces lignes cellulaires ne se forment pas, seulement, l'une après l'autre, mais que plusieurs lignes sont produites simultanément; nous en trouvons une preuve dans les écailles, qui dans leurs accroissements successifs, conservent les espaces marginaux, et dont les lignes cellulaires ou les cellules sont ainsi séparées en plusieurs groupes; nous citerons par exemple les écailles de *Cobitis fossilis*. Mais cet accroissement dans la périphérie n'expliquerait nullement, la grande épaisseur du milieu; nous en trouverons la cause dans la formation de la couche inférieure. Nous avons vu que celle-ci est composée de plusieurs lamelles. A' chaque accroissement se forment toujours des nouvelles lamelles: les canaux longitudinaux, qui parcourent toute l'écaille, apportent les sucs nécessaires pour qu'une formation uniforme d'une nouvelle lamelle puisse s'opérer dans toute l'étendue de l'écaille. Il s'ensuit, que les anciennes lamelles étant plus petites, l'épaisseur doit s'augmenter, à mesure que l'on se rapproche du foyer‡."

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* Philosophical Transactions, 1849, Part II. p. 435.

† Annales des Sciences Naturelles, vol. ii. p. 348.

I have introduced this long quotation, because, though abounding in errors, it is in some respects more correct than the hypothesis of other writers. The arrangement of the fibrous layers as well as of the fibres in each layer are accurately described. The longitudinal canals, we shall find, are no canals at all, and the *cells* which play so important a part in M. Mandl's views on *Lepidogenesis* are equally devoid of existence; we shall find that he has mistaken the nature of some solid calcareous granules which are formed within the fibrous tissues of his inferior layers, and conceiving them to be cells, has built upon them the hypothesis just quoted.

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* *Ut supra*, p. 354.

† *Ut supra*, p. 358.

‡ *Ut supra*, p. 363.

The publication of this memoir, controverting as it did, some of the opinions of M. Agassiz, elicited from that distinguished Ichthyologist an elaborate reply which was published in vol. xiv. of the same journal. He then considered that each scale consisted of but one substance, and that the existence of two layers, except in certain cases, was an error*.

Subsequently, however, M. Agassiz discovered his own error on this point, and became convinced that each of these scales did really contain two different structures. In his great work on fossil fish, whilst correctly pointing out the non-existence of the longitudinal canals of M. Mandl, which he considers to be merely grooves in the upper layer, he observes, "On se convaince alors que chaque écaille de Cycloide est formée de deux couches distinctes et superposées, qui toutes deux sont lamelleuses, mais dont le plan de stratification est différent, la couche interne étant continuée entière, tandis, que la couche externe, qui seule montre des lignes concentriques et une grande partie des sillons, est souvent interrompue." Still, however, denying the existence of fibres in the lower layers, which he says are transparent, sometimes yellowish, never containing cells or corpuscles, and are softened by maceration, he proceeds to describe what he believes to be the structure of the upper layer. "Au dessus de cette couche se trouve une seconde couche qui porte en elle les conditions des ornemens de l'écaille. La substance de cette couche est plus dure, plus cassante et plus transparente que celle de la couche inférieure; elle n'a jamais cette teinte jaunâtre, et dans la plupart des cas, on n'y distingue aucune structure particulière. Dans les écailles minces c'est comme un vernis séché et racorni, dont on aurait couvert la superficie de l'écaille. Mais dans les écailles épaisses des Labres, on aperçoit distinctement sur les coupes verticales, des traces de stratification, mais d'une stratification discordante avec celle de la couche inférieure. Le plan des lames ne répond pas à celui de l'écaille tout entière, mais elles sont couchées l'une sur l'autre comme les tuiles d'un toit, et plus ou moins imbriquées†." With reference to the corpuscles of M. Mandl, he observes, "Les corpuscules, qui dit on, forment une couche particulière au milieu de l'écaille, se voient, il est vrai, assez souvent, sous la forme d'ovales ou de carrés à contours ombrés et indistinctement limités;" but he doubts their being true corpuscles, and rather refers the appearance to some solution of continuity between the upper and lower tissues‡: the latter of these tissues he conceives to be not fibrous, but of a horny texture, and an exuded secretion from the sac into which he considers the lower and anterior portions of the scale to be fitted. After pointing out the resemblance that exists between the scales of Cycloids and Ctenoids, M. Agassiz goes on to give his interpretation of the nature of the peculiar teeth in the margin of the scales of the latter order. In some, which have only *one* marginal row of teeth, as Corniger and Myripristis, he thinks that "ce sont tout simplement des

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[*] *Ut supra*, vol. xiv. pp. 104, 105.

[†] Poissons Fossiles, vol. i. p. 70.

[‡] *Idem*, p. 72.

échancrures plus ou moins profondes du bord postérieur de la couche superficielle*." He observes others, however, which appear to be "corpuscules propres, implantés sur la couche supérieure de l'écaille; ce sont des formations tout-à-fait analogues à la couche supérieure et qui sont déposées sur cette dernière, comme les lignes et les bandes de la couche supérieure le sont quelquefois sur la couche inférieure†."

It will be seen from the details about to be brought forward, that both these distinguished observers have fallen into considerable errors, which affect alike their respective interpretations of the structure, and of the growth of Cycloid and Ctenoid scales. There is no doubt that M. Mandl is quite correct in distinguishing an inferior portion, composed of fibrous lamellæ, from the calcareous covering with which it is surmounted; and also in describing the fibres of each lamella as being parallel to each other, whilst they traverse those of contiguous lamellæ in a diagonal direction. But we shall find that no form of cartilage enters into the composition of these scales; their upper portions contain no cells or cartilage corpuscles; and so far from having been formed in the way described by M. Mandl, this superior calcareous layer consists of *two* very distinct substances, which differ alike in their structure and in their genesis. As an inevitable result, the whole of M. Mandl's hypothetical conclusions fall to the ground.

On the other hand, M. Agassiz has failed to detect either the fibrous nature of the inferior layers, or the existence of *two* distinct structures in the upper or calcified part of the scale; and whilst he has obviously seen the small calcareous granules which we shall find are distributed along the line of junction between the middle and lower layers, and which M. Mandl regarded as cells or cartilage corpuscles, he also has wholly mistaken their nature; the consequence has been the formation of an hypothesis which is as little tenable as that of M. Mandl.

The true structure of these thin scales can only be successfully studied by means of vertical as well as horizontal sections. The preparation of such sections from thin flexible scales, whose entire thickness is often not more than from $\frac{1}{200}$th to $\frac{1}{400}$th of an inch, is, as I have learnt from painful experience, only to be accomplished after long practice in the preparation of microscopic objects. Neither is it a task that can be well delegated to the lapidary. If the observations are to possess value and trustworthiness, the preparations must all be made by the observer himself; since an exact knowledge of the direction in which such sections traverse the scale is essential to the right comprehension and interpretation of the structures which they reveal. Without this knowledge all would be confusion and obscurity. Such sections may, however, be prepared even from the thinnest of scales. In all their essential characteristics, the Cycloid and Ctenoid scales are constructed upon the same plan. The differences which exist between them we shall find to be very trifling, and indeed some examples exist where it becomes difficult to determine to which of the two groups an individual scale belongs.

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* Poissons Fossiles, p. 73.

† *Idem*, p. 73.

The first scale to which I would direct attention is a very large one from the Bay of Dulse, on the western coast of Central America, and for specimens of which I am indebted to Sir Philip de Malpas Grey Egerton, Bart. I have not been able to learn the name of the fish to which it belongs, but from its large size, it furnishes such a beautiful illustration of the internal structure of this class of scales, that notwithstanding my ignorance of its name I avail myself of the information which it supplies: its natural size, and the aspect of its upper surface are represented in Plate XXVIII., fig. 1. It is of the Ctenoid type, but one of those examples which approaches very closely to the Cycloid form. Fig. 1 *a* is its posterior, and 1 *b* its anterior margin; each of which respectively present some peculiarities of structure. A few concentric lines are seen on various portions of its upper surface, which exhibits to the naked eye a frosted appearance, like that given to the vegetation by the hoar-frost on an autumnal morning. Posteriorly and laterally, bundles of divergent lines ornament this surface; they proceed somewhat irregularly, from near the centre towards the margin of the scale, being small grooves in its uppermost layer, which correspond with the "canals" of M. Mandl.

On making a vertical section of this fine scale along the line fig. 1, *a*, *b*, we obtain the structure represented in fig. 2, portions of which, still more highly magnified, are shown in figs. 3 and 4. We at once see that not only is the membranous lower layer (figs. 3 *a* and 4 *a*) distinct from the calcareous one, but that the latter portion consists of two distinct structures; a superficial (3 *c* and 4 *c*) and an intermediate one (3 *b* and 4 *b*). Fig. 3 represents a portion of the section (fig. 2) as seen at *a*, but viewed under a magnifier of still higher power. Inferiorly, it consists of numerous membranous laminæ (3 *a*) arranged in parallel horizontal lines. We learn from fig. 2 that these laminæ are most numerous in the centre of the scale, and diminish in number as we approach its margin, until we arrive at the extreme periphery, where but one exists. This is partly shown in fig. 4, which represents the portion of the section, fig. 2, as seen at *b*, but more highly magnified. We here see (4 *a*) the same membranous lamellæ as in fig. 3, only diminished in number and thickness, and which successively run out as we approach the margin of the scale. This margin is not quite reached at 4 *f*, but nearly so, since we find that the number of the visible membraniform laminæ is reduced to two.

Each of these membranous laminæ consists of numerous hair-like fibres, all those entering into the composition of one lamina being arranged in parallel lines; fig. 5 represents the horizontal aspect of portions of two such laminæ, showing the diagonal manner in which the fibres of each are arranged. The detached fibres seen at fig. 5 *a* exhibit a marked tendency to curl up in the way that those of the yellow fibrous tissue (ligamentum nuchæ) of mammals are well known to do.

Imbedded amongst these membranous laminæ, we see numerous isolated, lenticular calcareous bodies (figs. 3 *d* and 4 *d*), each of which exhibits a definite series of concentric lamellæ, with traces of a central longitudinal fissure. These small bodies have not been developed *between* two of the membranous layers, their development causing the latter tissues to diverge, but are the result of a calcification of the membranous laminæ, which they incorporate into their structure. They commence as a small calcareous atom, and increase in size by the external addition of new concentric laminæ, the direction of the latter not being parallel with, or having any reference to that of the laminæ of fibrous membrane which they so amalgamate; thus they are not depositions *from*, but growths *in* the membrane; which growths, as they increase in size, retain their primitive tendency to assume a lenticular form.

On carefully examining the middle layer of the scale (figs. 3 *b* and 4 *b*), we perceive that it is chiefly composed of an aggregation of such small lenticular bodies, which appear to coalesce as they increase in size; the newer calcareous additions sometimes lose their lenticular contour from having to enclose several lenticular granules which have so coalesced. This is seen at fig. 4 *e*.

As we approach the margin of the scale, we perceive that this middle layer gradually diminishes in thickness until it becomes reduced to a few scattered calcareous granules, like those which remain isolated in the membranous portion of fig. 3; thus this calcareous layer is not only thicker, but is more consolidated towards the centre of the scale than near its margin. On becoming thus confluent and consolidated, these granules assume a new aspect. The layer, thus formed, splits up into horizontal laminæ, which correspond, as to their direction, with that of the membranous laminæ prior to their calcification; the latter having apparently influenced the direction of the former. They also exhibit numerous small vertical subdivisions disposed at irregular intervals.

On examining a horizontal section passing through these secondary calcareous laminæ, we meet with an appearance like that represented by fig. 6. The outlines of the small lenticular granules are still visible (fig. 6 *a*), presenting varying degrees of distinctness. But in addition to these, the section is also traversed by numerous small and slightly curved fissures; the principal ones in each lamina (fig. 6 *b*) have a decided tendency to run in one direction, which, as in the case of the fibres of the membranous portion, is different in two contiguous portions. Minor fissures also exist, either fringing the larger ones at an acute angle (6 *c*) or forming an additional series, arranged at right angles to those which constitute the principal group.

In some instances these fissures appear to take their rise from primary ones which pass through the centre of many of the lenticular bodies (fig. 3 *d*); but more frequently they commence in small open spaces left between these bodies, which, when the specimen is mounted in Canada balsam, are seen to contain air. These fissures obviously correspond with the small vertical ones which intersect the calcareous laminæ in the section fig. 4 *e*. Fig. 6 exhibits their horizontal arrangement as seen in three contiguous laminæ, when viewed by transmitted light.

The third or uppermost layer (figs. 3 *c* and 4 *c*) is very different from the preceding one, both in its structure and in the way in which it has been formed. It is the one, by various modifications of which are produced all the ridges and tubercles which ornament the surface of the scale: along the greater part of the vertical section fig. 2, it exhibits the appearance, which, when more highly magnified, is seen in fig. 3 *c*; it has an undulating outline, and presents indistinct traces of a lamellar structure, the more external lamellæ being parallel with the superior margin of the section. The surface of this portion of the scale, when viewed horizontally by means of reflected light, is seen to be studded with innumerable minute tubercles.

When we approach the anterior margin of the scale (fig. 1 *b*), we find that the radiating lines already spoken of, are produced by the absence of the superficial tissue along their course, whilst in the intervening ridges it is of considerable thickness; each ridge thus formed is transversely subdivided by very numerous minor ridges, the upper edge of each of which is sharp and crenulated. This structure will be readily understood by a reference to fig. 7, which represents a small portion cut out and viewed as an opake object; 7 *a* are the lines along which the uppermost layer is wanting. These lines are homologous with those which M. Mandl regarded as nutrient *canals*, an error which we have already seen to have been detected and in part corrected by M. Agassiz. But whilst the Swiss philosopher very properly pointed out their nature, he also erred in considering that they passed through the entire calcareous portion of the scale and reached the subjacent soft tissues. It is perfectly true that they do so at the margin of the scale, where the middle layer is not yet developed, as seen in fig. 7; but towards the central portion of this and all analogous scales, where the middle layer exists, these grooves do not pass through it, except in some scales where at the anterior margin *all the three* tissues are cut through and the border of the scale is converted into a series of digitations, as is the case in that of the Perch: this however is merely an incidental circumstance, and does not affect the true nature of these grooves as they exist on the upper surface of the scale. The mistake made by M. Agassiz was one easily fallen into, he not being aware of the duplex character of the calcareous portion of the structure.

Fig. 7 *b* represents the ridges of the upper layer with their transverse crenulated subdivisions. These latter are the true homologues of the concentric lines commonly seen on the surface of Cycloid and Ctenoid scales, but which in this instance are only developed on the surfaces of the radiating ridges; 7 *c* are the extremities of the ridges as seen in the vertico-transverse section, whilst at 7 *d* we have an analogous vertical section, only made parallel to the superficial ridges, and in which the subjacent membranous laminæ (7 *e*) are seen rising in succession towards the surface of the scale.

These subdivisions of the superficial layer are the most conspicuous at the extreme anterior and lateral margins. As we approach the centre of the scale they become less definite, and are ultimately lost amongst the irregularly disposed superficial tubercles, of which the ridges are only a modified form. But at the posterior or free margin we find this upper layer assuming a new aspect. The superficial tubercles are not only more definite in their contour, but become isolated, and at the extreme margin assume the form of small, flat and regularly arranged hexagons. Their appearance is shown in fig. 8, which represents a fragment removed from this part of the scale, *a* being its posterior and *b* its anterior portions.

This uppermost layer covers the entire scale, even to its extreme periphery. In this respect, as well as in its internal structure, it differs from the subjacent calcareous portion. The latter becomes thinner, less consolidated, and finally ceases to exist at some little distance from the margins, as seen in fig. 4; on the other hand, the former exists on the upper surface of each of the membranous laminæ, as their margins successively rise towards the surface of the scale; and even at the periphery, where but one such lamina occurs, it is still covered over by the same superficial structure. This is a circumstance of importance, as tending to confirm the distinctness of the two calcareous structures. Though the way in which the superficial layer has increased in size is not very clear in this example, there are evidences, not only that it possesses a laminated structure, but that the lamellæ constitute so many additions that have been successively made to its upper surface. The examination of other scales, shortly to be noticed, will be seen to confirm this conclusion.

In the essential features of its internal structure, the scale now described may be received as a type of all the Cycloid and Ctenoid scales which I have examined. The increase in its size has evidently been accomplished by the addition of successive membranous lamellæ to the inferior surface of those previously formed; each new layer being rather larger than its predecessors. It is also obvious that the middle layer is produced by the formation and coalescence of the small lenticular bodies through the agency of which the calcification of the membranous laminæ is effected. This calcification permeates the entire extent of the upper and earlier-formed lamellæ, whilst with the exception of a few isolated granules, it has been confined to the margins of those which are inferior and of more recent growth; a distinction which will be readily comprehended on referring to the arrangement of these laminæ as seen in fig. 2. The scale of the Carp (*Cyprinus carpio*, Linn.) affords a beautiful additional illustration of the true nature of these structures, and more especially of the uppermost layer. A small portion of a vertical section of this scale, made in a direction parallel to the lateral line of the fish, is represented by fig. 9. The lower series of membranous laminæ are seen at 9 *a*; 9 *b* is the middle calcareous layer, and 9 *c* the superficial one. The lower membranous laminæ are arranged in precisely the same way as in the preceding scale, and the middle layer (9 *b*) only differs in the smaller size of the calcareous lenticular granules and in their being closely aggregated along the calcifying surface 9 *d*, instead of being also scattered through some of the lower membranous laminæ. After their coalescence and consolidation they break up, as before, forming a secondary stratification parallel with the original direction of the membranous layers; and when the inferior surface is viewed by transmitted light, it exhibits appearances which closely correspond with those seen in fig. 6.

On directing our attention to the uppermost layer, 9 *c*, we find a considerable difference presenting itself. When the scales of the Carp are *in situ*, the free portion of each, or that which is not covered over by its antecedent neighbours, is very rough, owing to the existence of numerous tooth-like points which project from its surface. It is this portion of the scale that has been traversed by the section fig. 9, and from it we learn that the existence of the superficial teeth is the result of an extraordinary development of the uppermost layer, which has not only produced these projecting appendages, but has also thickened the intervening portions. Nothing can be more distinct than the structures of the central and superficial tissues, as they exist in this scale. The superimposed lamellæ, of which the latter of these consists, are most obvious, even under a low magnifying power; and on tracing their direction, we see that it corresponds with the superficial outline of the section, evidently showing that its increment is effected at the upper surface. This appears to have been accomplished by the calcification of a very thin membrane with which the scale is covered, at the same time that the corresponding, though different, process was making additions to the *lower* surface of the middle layer along the undulating line, 9 *d*. The structure of these two portions is as distinct as their modes of growth. The middle tissue (9 *b*) exhibits the rough laminæ, filled with vertical fissures and traces of the lenticular granules of which it consists. The lamellæ of the uppermost one, on the other hand, appear to be perfectly structureless; consisting, apparently, of a smooth and homogeneous tissue, not to be distinguished, in the vertical section, from that seen in the ganoin of a *Lepidosteus* or some of the *Lepidoti*; thus the differences of aspect and of growth alike bring us to the conclusion that the scale of the Carp consists of three very distinct structures. At the *anterior* portion of the same vertical section, we find that the middle layer disappears as in the preceding scale, whilst the upper one rests immediately upon the membranous lamellæ. Here, though very thin when compared with its more largely developed posterior portion, the superior layer exhibits numerous minute tooth-like projections, which, whilst they exhibit the same laminated structure as the larger ones previously noticed, are more uniform in their size as well as more regular in their distribution. These projections are produced by the vertical and transverse section of the numerous concentric lines which give the cycloid aspect to this portion of the scale. It thus becomes manifest that these concentric ridges are not lines of growth, as thought by M. MANDL, but the result of a peculiar arrangement of the superficial tissue of the scale, a conclusion which accords with that arrived at by M. AGASSIZ.

The scales of the Pike, Salmon, and numerous other allied fish, are constructed on a similar plan to those already described, varying only in their minor details. A remarkably fine illustration of the type requiring a more special notice, is that of the Perch (*Perca fluviatilis*, LINN.), which also illustrates the peculiarities of the Ctenoid scale. In a vertical section of one of these, we observe that the number of the small lenticular granules which are isolated and dispersed through the membranous lamellæ, is much greater than usual. On inverting one of the scales, and examining these lamellæ by means of transmitted light, we perceive that the calcareous granules are arranged on a more uniform plan than in the examples previously described; they are not only in layers, but the individuals of each layer have a tendency to follow one determinate direction, being arranged with their longer axes parallel to one another.

Fig. 10 represents the appearance presented by a horizontal section of this portion of the scale. When highly illuminated, the membranous tissues become so transparent as to be almost invisible, and the distribution of the calcareous granules then becomes very obvious. Those occupying the lowest plane when the scale is *in situ* (but which the inversion of the scale brings the nearest to the object-glass), appear as innumerable minute and almost invisible granules. As we successively bring the superior laminæ into focus, we observe that the granules composing each layer become progressively larger as we penetrate the scale. When isolated, they ordinarily exhibit an obtusely fusiform contour, but as they grow in size they frequently become confluent. The increase in their size is produced partly by the confluence of previously detached individuals, and still more generally by the addition of new layers of calcareous matter round their exteriors. Indeed the latter process has apparently been the direct cause of the former condition.

In fig. 10, three such layers are represented as they appear in the inverted scale: 10 *a* is one of the lower series; *b* is a layer of larger granules, some of which (*b'*) have become confluent; and at *c* we observe a faint indication of a still higher series, which when brought into view are found to have coalesced, forming in fact the inferior surface of the middle tissue of the scale. This representation also shows, what I have already alluded to, that whilst all the granules composing one layer exhibit a uniform tendency to arrange themselves in one direction, those of different layers cross each other more or less diagonally. Bearing in mind the arrangement of the primary fibres of which these laminæ of membrane consist, it seems probable that the direction of these fibres influences that of the calcareous granules.

As we proceed horizontally from the centre to the periphery of the scale, we find a similar change to occur as when we pass from the upper to the lower layers. After a certain time, the additions to the inferior surface of the calcareous layer almost cease to be made in the centre of the scale; at all events, they do not continue to be developed as rapidly as in an earlier stage of growth, and as they still are nearer the margin of the scale. Hence many of the laminæ which have become calcified towards their periphery, continue to be membranous in their central portions, or, at the most, only contain a few detached granules; these however are often of a large size, and by their successive junctions with contiguous granules lose their fusiform contour and become more or less square or cuboid; in this state they are manifestly the objects noticed by M. Agassiz, "sous la forme d'ovales ou de carrés à contours ombrés et indistinctement limités," and which he mistook for accidental lesions which separated his superior from his inferior tissue.

As we leave the centre and proceed towards the circumference of the scale, its inferior membranous laminæ successively enter the field of vision. These contain more numerous granules, but they are of smaller size. As we come nearer to the margin, the granules become still more numerous, but exhibit a corresponding diminution in their bulk, until, at the edge of the scale, the otherwise transparent membrane assumes a hazy aspect from the presence of the innumerable minute calcareous atoms which are diffused through its substance.

Whilst the scale of the Perch thus supplies a beautiful illustration of the way in which the calcareous middle layer is gradually produced, it also explains the peculiar structure which induced M. Agassiz to constitute the Ctenoid a distinct group from the Cycloid order, distinguishing it by the teeth which fringe the posterior margin of the scale.

Fig. 12 represents a small portion from the surface of the posterior part of the scale of the Perch, *a* being its marginal extremity. The marginal teeth (12 *b*, *c*) are long, pointed posteriorly and dilated anteriorly; they are not raised vertically, like those on the scale of the Carp, but are depressed to the level of the surface of the scale. Behind each of these teeth we see that there exist numerous bases of similar teeth (12 *e*), which in the earlier stages of growth successively fringed the posterior margin of the scale, but of which the apices appear to have been worn away prior to the development of a new series; the abraded extremity of each tooth abutting against the dilated and concave base of its successor in such a way as almost to give the impression of a true articulation. These teeth are arranged in an alternating order, as if, when each new marginal growth had taken place, new teeth had only been added to the front of every other perpendicular row; thus the individuals *b* and *c* belong to different series, the former being apparently of a more recent formation than the latter; the remains of those in the more central parts of each row exhibit the same arrangement. Fig. 12 *d* is the soft membrane within which these teeth are imbedded.

Fig. 11 represents a vertical section of one of these perpendicular rows of teeth, showing their relation to the other tissues of the scale. 11 *a* is one of the unbroken marginal teeth, whilst *b* are the remains of those of earlier growth; *c* is a thin membrane which invests the *upper* surface of all the teeth; *d* is the peripheral portion of the lowermost of the membranous laminæ of the scale, and on the surface of which, if not actually within its upper tissues, the calcareous tooth *a* has been developed; *e* represents a superior lamina, in which the very minute granules forming the middle layer are beginning to appear.

On tracing these marginal teeth back to the middle of the scale, we find that they are but modifications of its third or uppermost layer, thus corresponding with figs. 3 *c* and 4 *c*, being more especially the exact homologues of the tesselated hexagons seen in fig. 8, which, it will be remembered, represents a similar fragment taken from the corresponding portion of the large scale, fig. 1.

The question which now suggests itself is, what relation does the superior investing membrane (11 *c*) bear to the inferior fibrous portion (11 *d*)? We have already seen that all the scales just described require the existence of a superficial membrane to render the growth of their superior calcareous layer intelligible. This we found to be especially the case in the scale of the Carp, though the latter is but a highly developed example of the common type. In that of the Perch we have demonstrative evidence of its existence. Whether it is, in the first instance, merely the upper portion of a lamina (11 *d*), within the substance of which the teeth *a* and *b* are developed, or whether it is an *inflected prolongation* of the same lamina, modified in its structure, and which, after turning round the apex of the tooth, 11 *a*, is extended over the entire surface of the scale, I am unable to say. Analogical reasoning, based upon the structure of the ganoid scales, would lead us to the latter conclusion, in which case each new lamina of membrane, though apparently added to the inferior surface of the scale only, would really enclose the entire structure like a capsule. If, on the other hand, the former be the real interpretation, it is obvious that the *upper* surface of this superficial membranous structure must possess the power of perpetuating its existence by continuing to be developed superficially, as its *lower* fibres become gradually calcified and amalgamated with the substance of the uppermost calcareous layer. Be the process of its genesis what it may, we have here demonstrative evidence of the existence of such a superficial film of soft membrane as is essential to my hypotheses, accounting for the peculiar structure and growth of the uppermost layer. The production and growth of fibrous tissues has long been one of the most perplexing subjects in physiological science; and the peculiar forms of fibrous tissue existing in these scales, certainly do not diminish the difficulties with which the subject is already invested. Nothing here indicates a cellular origin of the fibres.

In the scale of the Grey Mullet (*Mugil Capito*, Cuv.), the posterior marginal teeth, though also pointed, are much shorter and broader, verging even to a rhomboidal form. Their persistent bases, as seen at a little distance from the margin of the scale, have received new calcareous additions to their upper surface, in the form of a crest of minute mammillæ, which are especially evident at the posterior border of the new growth. On examining the anterior margin of the same scale, we see that the concentric lines common to nearly all cycloid and ctenoid scales, are smooth at the periphery, whilst at a little distance from it, they also have received additions of the same mammillary character. These additions are the most obvious along the raised ridges which produce the tooth-like projections seen in fig. 3, only in the Mullet, as in the Perch, these ridges are much more acute, corresponding in this respect to the small transverse crenulated subdivisions of fig. 7. In these fishes, also, the continuity of these ridges is only interrupted by a small number of the grooves radiating to the anterior margin of the scale, so many of which exist in the Mexican example, 7 *a*.

An important homological question now suggests itself: what relation does this third tissue bear to those existing in the ganoid scales especially of Sauroid and

Lepidoid Fishes? I confess I see no way of distinguishing it from the true ganoin itself, using the term in the restricted sense in which it was employed throughout my last memoir already referred to. If the surfaces of these ganoid scales, instead of being smooth, as is usually the case, had been fretted and sculptured with as infinite a diversity of minute points and ridges as are seen on those of Cycloid and Ctenoid fishes, I suspect that the former would have lost very much of the shining aspect to which they owe their name. It appears to me that there is no real difference between the superficial calcareous layer of a perch or a salmon, and the ganoin of a *Lepidosteus*. This is, however, a point on which differences of opinion will doubtless exist; I confess that it is equally difficult to detect any difference between the same tissue as seen in the vertical section of a scale of a carp, and the laminæ in some of the bones of a pike and other osseous fish, the bones of which contain no lacunæ. In a subsequent portion of this memoir we shall find that the latter are merely the calcified lamellæ of a periosteal membrane, exhibiting no visible traces of minute structure. The lamellæ covering the scale of a carp are neither more nor less than this.

Additional light is thrown upon this portion of our subject by the study of some other scales, to which I will now direct attention. One of the most curious of these belongs to a species of *Balistes*, one of the File-fish, in the collection of Sir Philip Egerton.

In their external aspect these scales bear a close resemblance to those of many ganoid fish, exhibiting the rhomboidal form and peculiar tessellated arrangement seen in the members of that group, in which M. Agassiz has arranged it. On making a vertical section of one of these scales, we find that in its internal structure it approximates closely to the type prevailing amongst the Cycloids and Ctenoids, retaining however one or two curious points of the resemblance to the Ostracionts. A representation of a vertical section, made parallel to the lateral line of the fish, is given in fig. 13; *a* is its anterior extremity, which is overlapped as far as *b* by the free margin of the antecedent scale; *c* is its posterior border, the sloping inferior surface of which reposes in like manner upon the anterior portion of the scale behind it. As in the Cycloids, we have three very distinct horizontal tissues, lower, middle and upper.

The lower one (fig. 13 *d*) consists of parallel laminæ of membrane; but in addition to its horizontal fibres, we here see that there are numerous thick fibres which pass obliquely upwards from layer to layer, binding them together; we shall afterwards find that these oblique fibres belong to a peculiar type prevailing amongst the Ostracionts, where they produce some very remarkable and beautiful structures. In the present example I do not perceive that their existence materially affects the conformation of the middle layer, fig. 13 *e*, which is a calcareous one, formed in precisely the same way as the corresponding layer amongst ordinary Cycloid and Ctenoid scales, viz. by the development of small round and lenticular granules within the fibrous tissues of the membranous laminæ. In their aggregation these granules leave a larger number of open interstices than occur in those scales already described. This may partly be owing to the existence of the oblique fibres just referred to. In other respects they present no material distinctive feature. The layer thins out as we approach the margin of the scale. The consolidated tissue first disappears, leaving only a layer of minute detached granules, which also soon cease to exist, and the marginal portions of the scale consist only of the uppermost and lowest tissues.

It is the peculiar aspect of the superficial layer which gives the chief interest to this curious scale. That portion of its external surface, which, when *in situ*, is not covered over by the antecedent scales, exhibits an aggregation of numerous large papillæ. The vertical section shows us that these are produced by an extensive development of the upper layer, which is so thick in this species, that it occupies one-third of the vertical diameter of the scale. At 13f', where the preceding scale has rested upon it, this tissue is level and smooth; but at its anterior half its development has produced the large tubercles already referred to. All these various portions consist of numerous minute lamellæ, arranged in precisely the same way as the homologous ones in the scale of the Carp, fig. 9 *c*. The growth of the tissue has evidently been effected by the addition of new lamellæ to the upper surface of the pre-existing ones.

These lamellæ are perforated by a dense network of anastomosing canals which run in every direction; they are the largest at the inferior portion of the tissue, where it is contiguous to the middle layer, and where they exhibit a marked tendency to radiate from the centre to the circumference of the scale. These give off numerous anastomosing branches, which, as they ascend, diminish in size, and finally open by myriads of minute apertures at the external surface.

This peculiar structure is wholly new to me. It is very different from those dentine-like tissues, to which, in my former memoir, I applied the name of Kosmine. The anastomosing tubes have more of the character of the Haversian canals seen in the vertical sections of the scale of *Megalichthys*, only the lamellæ which they penetrate contain none of the lacunæ seen in that very beautiful example. They bear even a still closer resemblance to the small canals which penetrate the true *osseous* dorsal spines of some Siluroid fish, which pass through lamellæ crowded with lacunæ, and are obviously the homologues of the true Haversian canals of the higher vertebrata. If the lacunæ and their canaliculi were absent from the Siluroid spine, the canals in the two examples would correspond as closely as possible; we shall afterwards find that the existence of lacunæ is not at all essential to a true osseous structure, inasmuch as they are absent from the bones of a large majority of the osseous fish: they are an adjunct, but not a necessary one, especially amongst fishes; consequently this superficial structure in fig. 13 becomes but a slightly modified form of bone. It is equally obvious that it is also the homologue of the corresponding portions of the scales of the Carp, Perch and other Cycloid and Ctenoid fish; only we have here, in addition to the lamellæ which it possesses in common with the examples just cited, these permeating and anastomosing canals. In their respective classifications, Agassiz, Müller and Owen have alike recognized the "ganoid" character of the scale of *Balistes*; hence this "ganoid" structure, homologous as it is with the superficial tissue of the scale of the Carp, becomes a strong argument in favour of my idea that the uppermost layer of the Cycloid and Ctenoid scales is identical in its character with the ganoin existing on those of *Lepidosteus*, *Lepidotus*, and their allies.

We obtain an additional illustration of the way in which these structures are modified and linked together from the scale of the Flying Gurnard (*Dactylopterus volitans*, Lacep.). Anteriorly these scales present a thick and expanded base, but posteriorly they taper away to a thin and narrow point. In the interior of the scale is a number of large irregular cavities with connecting channels of communication, and which give off numerous irregular anastomosing canals, running in every direction. On making a vertical section through the centre of the scale, parallel with the lateral line, we obtain the result represented in fig. 14.

With the exception of a slight modification of part of its inferior surface, this scale is obviously composed of one uniform tissue, which approximates more closely to the common form of bone as it exists amongst the osseous fishes than in any other example with which I have met. In its essential features it also bears a close resemblance to the uppermost layer of the scale of *Balistes*, fig. 13 *f*. It consists of numerous translucent laminæ variously inflected; the external ones lying parallel to the contiguous surfaces, whilst the internal ones follow the outline of the large central cavities which they invest. They are perforated by the canals, Plate XXIX., fig. 14, *a*, *b*, *c*, which run in every direction and communicate with the various surfaces; they are prolonged alike into the thin anterior basilar expansion, 14 *d*, which is implanted in the soft integument and into the posterior acuminate extremity of the scale, 14 *e*. Inferiorly, the horizontal lamellæ (14 *f*) are perforated by a number of branching tubes, which coalesce as they ascend, and finally open into the large central cavity, converting this portion of the scale into a tissue resembling kosmine.

If the uppermost layer of the scale of *Balistes* be really ganoin, as thought by M. Agassiz and Professor Owen, and of which I have no doubt, then nearly the whole of the scale of *Dactylopterus* consists of the same tissue. I am unable to see any essential difference between the two examples. On the other hand, if we compare the structure of this scale with that seen in all the bones of the endoskeleton of the Pike, and especially with the central portions of the epitympanic (fig. 39) or the articular extremity of the opercular (fig. 40), we shall find that no essential difference exists between them, beyond a slight variation in their respective densities and degrees of hardness. In both we have the same inflected membraniform lamellæ, surrounding similar central cavities, and perforated by analogous Haversian canals; whilst a very considerable degree of resemblance exists as to their respective modes of growth, both being produced, as we shall afterwards find, by the analogous calcification of an investing periosteum; only whilst in the cases of the bones we shall find that the growth is based *upon* a matrix of cartilage, we have not the slightest evidence that such a tissue ever entered into the composition of the scale. At the same time it is not easy to understand how such large cavities as exist in the interior of the latter structure can have been formed.

The same lamellæ, which at fig. 14 *a*, *b* and *c* are penetrated by Haversian canals, and appear to be at once osseous and ganoid, at 14 *f* are penetrated by a different set of tubes converting them into kosmine, and allying them with tooth-structures. Connecting this fact with the analogous ones published in my preceding memoir, we can scarcely escape the conclusion that bone, ganoin, kosmine, dentine and the enamel of fishes' teeth, are but modified forms of one common tissue; and though for the purpose of facilitating the interchange of ideas it is necessary to distinguish these modifications by various names, we must bear in mind that no clear lines of demarcation can be drawn between them, or definitions given, which will not in numerous instances fail to be strictly applicable. Inosculating examples occur which may be classed with several of the tissues, and yet without agreeing exactly with any one. This statement applies to each of the characteristic properties exhibited by individual examples of these structures, and of course has reference to the relative degrees of glossiness presented by their external surfaces, as well as the hardness, thickness, colour, and transparency of their respective lamellæ. Hence it is perfectly possible to have "ganoin" without glossiness. We see something approaching to it in the fossil scales of *Dapedius*, and that such is really the case in examples recorded in the preceding pages, I have but little doubt.

Fig. 15 represents a vertical section of the scale of *Loricaria cataphracta*, Linn., a Siluroid fish from Brazil, for which also I am indebted to Sir Philip Egerton. The substance of the scale is of a truly osseous texture, closely resembling that seen in *Acipenser* and *Lepidosteus*, only wanting the curious parallel tubes seen in the latter of these examples. It consists of numerous lamellæ, arranged like those of the *Lepidosteus*. Towards the posterior margin of the scale (fig. 15 *a*) they are wholly parallel to the inferior surface; but at its anterior portion (fig. 15 *b*), where it has supported the free edge of its anterior neighbour, the laminæ turn upwards, and are prolonged over a portion of the upper surface. In this respect its conformation is almost identical with that of the *Lepidosteus*, which it also resembles in its numerous quadrate lacunæ, with their divergent canaliculi, spread out in layers between the lamellæ. An abundance of minute lepidine tubes penetrate the structure from below (fig. 15 *c*). In addition to these tubes, there are many large Haversian canals (fig. 15 *d*), resembling those which in my preceding memoir I described as existing in the scale of *Holoptychius sauroides*.

These canals run in various directions, but are especially spread out as an irregular network (15 *e*), immediately below the upper surface of the posterior half of the scale. The latter portion is thickly covered with large mobile recurved teeth, arranged in rows which are more or less parallel with the mesial line of the fish*. Fig. 16 is a still more highly magnified representation of one of these teeth, with the basis upon which it is planted. Like the majority of the dermal teeth of fish, it is simple, containing an elongated pulp-cavity (fig. 16 *a*), from which numerous kosmine tubes are given off; at its lower extremity (16 *b*) it suddenly becomes contracted, the pulp-cavity being prolonged through the narrowed projecting base (16 *c*).

On the surface of the scale there are numerous small circular cavities (16 *d*), which communicate inferiorly with branches from the network of Haversian canals. Each cavity is surrounded by a narrow projecting rim (16 *e*), upon which the flanging shoulders of the tooth rest, whilst its constricted base is fitted into the inclosed hole, thus producing an arrangement which closely resembles a ball-and-socket joint, and which must allow of a considerable degree of motion in every direction. The tooth is apparently held in its place by a capsular expansion of the membrane (fig. 16 *f*) which covers the surface of the scale. From the direct communication that exists between the cavities (16 *d*) and the Haversian canals (16 *g*†), it is obvious that the latter furnish the pulp-cavity with its nutrient supplies. The one opens directly into the other. It only requires the tooth to be fixed instead of moveable, and depressed instead of acuminate, in order to render it the exact homologue of one of the areolæ in the kosmine of *Megalichthys*. It also reminds us of a very similar connection which exists between the ramified dentinal canals of the tooth of the Pike, and the corresponding ramifications of the Haversian canals in the subjacent bone.

By studying the structure of the above scale, along with that existing in Cycloid and Ctenoid scales, we are enabled to comprehend what was previously obscure, viz. that of the scale of *Macropoma Mantelli* from the Chalk. It is now obvious that the vertical section figured in my last memoir‡ reveals a structure which is identical with that of a cycloid fish; only in the process of fossilization, the lowest or membranous layer has disappeared, leaving the calcareous laminæ of the middle layer, as seen near the margin of one of these recent scales. But in the *Macropoma*, instead of being merely covered with a layer of what I have regarded as ganoin, as in the Carp, Perch, &c., this tissue is surmounted by an abundant development of kosmine, in the form of large pointed teeth§, which closely resemble those of the Siluroid fish just described. They differ little in the two cases, beyond the fact, that whilst in the Siluroid the teeth have contracted bases and are moveable, in the *Macropoma* these bases are expanded, and firmly fixed upon the upper surface of the scale. We thus see how the types of several groups of scale structures are blended together in the latter fish. Whilst upon a truly *cycloid* scale are fixed numerous *placoid* teeth, in its perfectly ossified and kosmine-covered opercula, it approaches to *Dapedius granulosus* and other allied forms belonging to the *ganoid* order of M. Agassiz. Such is the extraordinary way in which the few primary elements entering into the composition of the ichthyal skeleton, are modified and combined in order to produce the greatest possible diversity in the resulting structures! How impossible must it be for any truly physiological system of classification to be framed, if it is based only on the relative degree in which any one of the elements composing the dermal skeleton are developed!

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* Some similar teeth have been described and figured by M. Agassiz, as existing on the scale of *Hypostoma placostomus*, Poissons Fossiles, vol. i. tab. H. fig. 31 and 32. He speaks of their constricted bases and the circular holes into which they are fitted, but refers to the latter as existing in the enamel (émail). In the present scale we have no such substance; it is entirely composed of true osseous tissue; the details of the structure upon which the teeth are fixed are not shown in a very definite manner in the figures.

† Their continuity does not happen to be shown in the specimen from which the above figure was drawn.

‡ Philosophical Transactions, 1849, Part II. tab. 43, fig. 27.

§ *Ut supra*, fig. 28.

I have now to describe some still more singular and beautiful textures existing in the scales or dermal plates of fish belonging to the genus *Ostracion*. It is well known that their exoskeleton is composed of numerous small angular pieces, which do not overlap each other, as is the case with most other dermal scales, but are fitted side by side like the tiles of a tessellated pavement, on the plates constituting the shell of an *Echinus*. I am not aware that their structure has been subjected to any investigation beyond that of M. Agassiz, briefly noticed in the Poissons Fossiles, where, he observes, "la couche inférieure est une substance *cornée*, déposée par lames, et affectant des formes très-diverses dans la même écaille; elle est recouverte d'une couche épaisse de dentine très-bien caractérisée par ses tubes calcifères ramifiés, qui ressemblent en tout aux tubes calcifères des dents." The idea which this distinguished savant had adopted as to the *horny* nature of the fibrous portions of Cycloid scales, has again biassed his judgement and led him into a similar error in interpreting the appearances presented by the dermal plates of *Ostracion*. He gives a sketch* of the vertical section of a scale of *Ostracion triqueter*, the leading outlines of which are very correct, but the more minute structural details are not delineated.

Fig. 17 represents the upper surface of one of these scales (double the natural size), for which I am indebted to J. E. Gray, Esq. of the British Museum. As in *Balistes*, this surface is usually covered with large tubercles. The inferior surface on the other hand is smooth, and exhibits numerous concentric lines, like those represented by fig. 18; only towards the centre of the scale the angular concentric lines become less distinct than in this section, owing to the intervention of successive laminæ of fibrous membrane. Numerous minute apertures, which exist in these laminæ, are the orifices of canals which pass obliquely upwards towards the centre of the scale.

Fig. 19 represents a vertical section of one of these structures made in the direction of the dotted line, fig. 18 *a a'*. On looking at the latter drawing, it will be perceived that, whilst in its central portion the section runs parallel with one of the concentric lines a little to the right of the centre of the scale, at its two extremities it more or less directly traverses those of the two contiguous series.

From the above section, we learn that this curious scale is partly calcareous and partly membranous; the two substances being arranged in alternating horizontal layers and vertical subdivisions. The dark concentric lines (*c* in fig. 18) are *membranous* portions, whilst the light intervening spaces (18 *d*), as well as the radii (18 *e*) proceeding from the centre to each angle of the scale, are calcareous. In this preparation a little of the lower surface has been ground away, in order to bring the arrangement of the more internal parts into view. In fig. 19, the upper surface (*a*), the vertical pillars (*b*), the horizontal lamellæ (*c*), as well as the oblique ones (*d*), in which the two last series (*b* and *c*) meet, are all calcareous. On the other hand, the central portion (*e*), the square lateral areolæ (*f*), and the inferior dark longitudinal lines (*g*) are permanently membranous. It will thus be seen that the scale consists of a combination of membranous and calcareous tissues, variously arranged. On examining these different portions still more minutely, beautiful structural details reveal themselves; some of these will be better understood after making a reference to fig. 20, which represents a still more highly magnified view of a portion of fig. 19. The uppermost tissue of the scale, or that to which the superficial tubercles seen in fig. 17 belong, consists of very thin superimposed lamellæ (fig. 20 *a*), traversed by numerous minute branching tubes, which open at the surface of the scale. The outermost of these lamellæ are arranged parallel to the superficial undulating outline of the section, which circumstance, combined with the direction followed by the permeating tubes, leaves no doubt that the growth of these layers, like that of ordinary ganoin, has been the result of successive additions made to the upper surface of the scale.

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* Poissons Fossiles, vol. i. tab. H.

The structure thus produced is obviously one form of kosmine; but beneath it there is another form which assumes a very different arrangement. Numerous large branching canals (fig. 20 *b*), fringed all round with minute tubuli, enter at the margin of the scale, and proceed towards its interior, traversing the concentric plates seen in fig. 18, nearly at right angles. Their general direction will be best understood on a reference to fig. 21, which represents one angle from the horizontal section of a scale, made in the plane of this series of canals. In the latter figure, they commence by open orifices (21 *a*) at each margin of the scale, and proceed at right angles to that margin, and in nearly parallel lines, towards its interior; sometimes they are simple throughout, whilst at others they unite with contiguous canals by means of anastomosing branches. Owing to their parallel direction, few of these reach the centre of the scale, but meeting similar canals coming from the opposite side, unite with them almost at right angles; whilst a single trunk (fig. 21 *b*), running along the top of the radiating calcareous septum (fig. 18 *e*), combines all these various branches into a common system of canals, which furnish the upper tissues of the scale with a portion of their nutrient fluids. Sometimes these canals send small branches upwards (fig. 20 *c*), which open at the exterior of the scale, whilst others, proceeding in the opposite direction, open at its inferior surface. At fig. 21 *c*, the minute kosmine tubes given off by these canals have been omitted from the drawing, in order to show the undulatory lamellæ or lines of growth, which run parallel with the external surface, as we also saw to be the case in the vertical section, fig. 20 *a*.

On returning to the latter preparation, we at once see that the square membranous compartments (19 *f* and 20 *d*) are really the concentric lines (18 *c*) cut across, whilst the intervening septa (20 *e*) correspond with the concentric calcareous plates (18 *d*). In the former, some large bundles of fibres are seen to proceed horizontally inwards; and we shall subsequently find that the dark lines traversing the vertical calcareous septa in the same direction, are produced by prolongations of these fibres which pass through the septa without becoming calcified. I have already shown that the large central area (19 *e*) is the result of the unilateral direction taken by the section (fig. 18 *a a'*), which here traverses one of the membranous compartments (19 *f*) *longitudinally* instead of *transversely*, as is the case with those right and left of it. The numerous small orifices at fig. 19 *k* are those of the kosmine canals, 18 *h* and 20 *b*, which are here traversed at right angles, owing to the same cause.

Below these concentric compartments we find a solid calcareous layer, 19 *i* and 20 *f*, forming a conical, six-sided dome, the margins of which approximate towards the inferior surface of the scale as they approach its periphery. It is perforated by kosmine canals, 19 *i'* and 20 *g*, resembling those existing in the upper tissues, but here they are neither so numerous nor so extensively developed, being more confined to the marginal portions.

Beneath the dome-shaped septum there are several calcareous laminæ, 19 *c* and 20 *h*, extending from side to side, the upper ones being necessarily smaller than those which are inferior. At their margins they are continuous with the substance of the conical dome. Like the vertical septa, these laminæ are also penetrated by bundles of uncalcified fibres, 20 *i*.

It is impossible to study the distribution of these calcareous tissues without being struck with the way in which they are adapted to the purpose of strengthening the scale, and by maintaining its slightly arched form, enabling it to resist a large amount of external pressure. The dynamic principle displayed in the arrangement of the horizontal laminæ (19 *c*), strengthening the dome (19 *d*), is precisely the one acted upon in the construction of the light iron roofs of modern railway stations; whilst the small compartments with which the dome is surmounted, vividly remind us of the "cells" which constitute so important a dynamical element in the construction of those recent triumphs of engineering art,—the tubular bridges. Surely the engineer might study some of nature's contrivances for resisting pressure with great advantage, even though embodied in so insignificant a structure as a fish's scale.

Before proceeding to a more minute examination of the fibrous membranes, I would direct attention to a modification of these calcareous structures, as seen in the abdominal scales of *Ostracion cornutus*, for examples of which I am again indebted to Sir PHILIP EGERTON.

The dermal plates of this species are constructed on the same general plan as those just described; but they exhibit a little variety in the arrangement of their details. There only exist two or three of the vertical calcareous septa, seen to be so numerous in fig. 19, and a corresponding difference exists in the number of the subjacent horizontal laminæ. The superficial portion also presents some points of difference. Fig. 22 represents a vertical section of the upper textures, as they appear at the extreme margin of the scale. The concentric lamellæ (22 *a*) are here seen to be largely developed and perforated by even a still greater profusion of minute tubes, the orifices of which open at the external surface. These tubes give off numerous branches, and an immense number of minute recurved, falcate twigs, which are peculiar and characteristic.

The extraordinary development of this superficial system of tubes is compensated for by the absence of the secondary twigs fringing the large canals (22 *b*), which enter from the margins of the scale. The principal trunks recur, and are distributed in the same way as before; but the small branches which gave them their character of kosmine tubes are wanting; they are thus reduced to the condition of mere Haversian canals. The terminal twigs of the superior series of tubes begin to appear almost immediately above, instead of at a distance from them, and thus traverse a part of the space which, in the previous example, was occupied by the tubuli branching from these horizontal canals. The subjacent calcareous portions resemble those already described.

The singular structure of the membranous tissues of the decalcified scale of *O. cornutus* affords a good illustration of that of the preceding species, and of the group in general. Fig. 23 represents the centre of a vertical section of a scale subsequent to its immersion in weak hydrochloric acid. From this specimen we perceive that the distinctions seen in the scale prior to decalcification, partly exist in the membrane also. The upper tissue (fig. 23 *a*) still exhibits its wavy lamellæ, and traces of the vertical tubuli. The horizontal series of canals (23 *b*) are also conspicuous, communicating with the large vertical prolongations (23 *c*′) which proceed downwards towards the lower surface of the scale. The two lines (23 *dd*) sloping away right and left in the downward direction correspond with the calcified dome-shaped layer (*i*) of fig. 19. The lower portions of the decalcified scale consist of numerous thick laminæ, which are horizontal in the centre (23 *e*), but turn upwards as they successively reach the line 23 *d*. Thus we see that the dome-shaped layer divides the membranous as well as the calcareous laminæ into two series; those which are superior to it being vertical to, and those which are inferior being parallel with its surface. The horizontal and vertical portions are, however, continuations of each other.

Each lamina, as seen at 23 *e*, consists of two sets of fibres; when a horizontal section is made near the centre of the scale, those belonging to one of these series are observed to form its chief substance; they are very minute, and arranged horizontally in parallel lines, being only deflected here and there so as to allow bundles of the second series to pass between them in a more or less vertical direction from one lamina to another. The latter series are especially obvious in the central and upper portion of the section (fig. 23), from which point they proceed in divergent lines towards its inferior border. As the *horizontal* fibres of each lamina approach the line 23 *d*, they gradually lose their parallelism, and unite to form bundles of various thicknesses; owing to the manner in which the fibres forming each bundle redistribute themselves and contribute to the formation of other divergent bundles, there is produced a curious reticular structure with oval or fusiform meshes. On examining the upturned extremities of the laminæ, we discover the same tissues, only in a modified form which exhibits great beauty, whether viewed in reference to its adaptation to the primary purpose of strengthening the organism, or to the exquisite appearance of the interlaced fibres. Fig. 24, Plate XXX., represents a vertical section made almost parallel with the outer margin, but with sufficient obliquity to cause it to traverse three of the vertical laminæ at a very acute angle. Fig. 24 *a* is the superficial tissue (kosmine), and *b* the subjacent horizontal canals, divided nearly at right angles to their course; *c* are the lower or horizontal portions of several laminæ; *d*, *d* represent the three vertical laminæ, each consisting of an elaborate network of interlacing fibres; the latter being continuations of those which form the parallel horizontal series in the horizontal portions of the laminæ, and which have been already shown to assume a reticular arrangement as they approached the line fig. 23 *d*. Here this alteration in their distribution has attained its climax. The structure is not produced like those woven fabrics, where a warp and a weft interlace one another in opposite directions; the fibres, originally spread out on one plane like the threads of a warp, are looped up into bundles at one point, only to be separated again and redistributed at another, when the individual fibres enter into the composition of new and divergent bundles, the interlacings of which leave numerous small meshes between them*. These tissues appear to be more dense and strong towards the outer, than at the inner surface of each lamina.

The meshes thus left are occupied by bundles of the second series of fibres, which pass through them at right angles. Corresponding with those which radiate from the centre of the section (fig. 23), and traverse the horizontal laminæ, they are still more fully developed in the upturned vertical portions of each layer. Though the fibres are aggregated into large and strong bundles, they do not interlace so as to form a network; all the fibres which enter into the composition of one fasciculus, continue to do so; and even the separate bundles retain their parallelism with each other. Fig. 25 represents a portion of one fasciculus, from which it will be seen, that whilst it is flattened out at intervals (25 *a*), the intervening parts are cylindrical (25 *b*). The bundles of fibres, thus constructed, proceed horizontally from the centre to the circumference of the scale, following the direction of the canals in fig. 21. Fig. 26 represents their appearance in a *horizontal* section of a portion corresponding to that divided *vertically* in fig. 24 *d*. 26 *a*, *a* are the outer and more consolidated portions of the respective vertical laminæ, and correspond with 24 *d*. 26 *b*, *b* are their inner and more lax portions, corresponding with 24 *e*. These vertically disposed tissues are traversed by the numerous horizontal bundles of fibres, 26 *c*, which proceed, as already described, towards the periphery of the scale. Whilst the flattened portions of the latter pass through the meshes of the dense outer tissues, 24 *d* and 26 *a*, their more contracted and cylindrical parts traverse the inner and looser textures of the corresponding laminæ, 24 *e* and 26 *b*.

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* The fibrous membrane lining the canal of the chorda dorsalis of the common Dog-fish (*Spinax acanthias*) exhibits a very similar structure.

At their inner extremities, nearly all these latter bundles of fibres *appear* to terminate along lines which correspond with the radiating calcareous septa, fig. 18 *e*, but in reality they are only deflected in the direction of these lines towards the centre of the scale. A reference to the corresponding direction of the kosmine canals in fig. 18 will render this point intelligible.

After decalcification, we are no longer able to identify either the vertical or horizontal laminæ which were originally calcareous; their membranous portions have evidently no peculiarity of structure distinguishing them from those which were not calcified. We thus find that all the various complicated tissues existing in the lower portions of this curious group of scales, consist primarily of but two sets of fibres, running in different directions. The same arrangements exist in the decalcified scales of all the Ostracionts which I have examined. The next question to be decided is the relation which the calcareous elements bear to these different sets of fibres. Whatever may be their modifications, it is only those fibres which, in the central and inferior laminæ, are horizontal and parallel, that ever do become calcified. On exposing some of the vertical septa (18 *d* and 20 *b*) to the action of boiling Liquor Potassæ, I got rid of the merely membranous portions, and preserved the calcareous elements intact. Fig. 27 represents the lateral aspect of a fragment of a septum thus acted upon, which is obviously nothing more than a calcification of the interlaced fibres seen in fig. 24 *d*. It is a calcareous network with numerous lenticular meshes, 27 *a*, through which the flattened portions of the bundles of horizontal fibres have passed without calcification. The calcareous margin of each mesh is incised by a number of minute vertical fissures, 27 *b*. I have not been able to ascertain with certainty what function these fissures have fulfilled; but I suspect that separate fibres raised from the surface of the common bundle have fitted into these small incisions, which would thus contribute in a very important manner to the fixation of the bundle in its place and increase the strength of the organism.

The horizontal laminæ (20 *i*) are perforated, and penetrated by the uncalcified vertical fibres, in precisely the same way. In the vertical section of the extreme margin of one of these scales, fig. 22, we see that these horizontal bundles penetrate the lower portions of the uppermost calcareous layer. Thus they are seen passing outwards at 22 *d*, whilst at *e* their transversely divided extremities are rendered visible, owing to the direction of the line of section, as explained at page 662. They do not ascend as high as the horizontal canals, 22 *b*. The laminæ which enter into the composition of these, and of the superincumbent tissues, consist wholly of prolongations of the reticulated fibres, fig. 24 *d*, which here cease to be aggregated into bundles, lose their reticular distribution, become much contracted in size, and spread out, forming thin membranous laminæ which are turned inwards, so as successively to invest the upper surface of the scale, and where, by their calcification, they form the large tubercles with which each is covered. Thus we perceive that amidst all their singular modifications, the scales of Ostracionts maintain a close conformity to the type prevailing amongst those of the ganoid order of M. Agassiz.

Another question to be considered bearing upon these structures, has reference to their mode of growth. This however is one which continues to be involved in some obscurity. That the new laminæ have successively invested the entire scale does not admit of a doubt. The origin of the new layers of fibres is a difficulty which affects the history of these scales in common, not only with those of other groups of fishes, but with all periosteal growths whatever. The additions to the second class of fibres forming the radiating bundles, appear to be made to their extremities, partly by the prolongation of the pre-existing fibres, and partly by the gradual incorporation of new ones. The latter process would of course be rendered necessary by the constantly enlarging area which they would have to occupy. On examining the line of junction between the margins of two contiguous scales, the large horizontally disposed bundles of fibres (26 *c*) may be seen projecting from the edge of each plate into the intervening space. This is obviously the place where in some way or another the additions to their length are made. In the inferior margin of several specimens I have observed an appearance like what I have represented at fig. 24 *f*, where an investing membrane appears to be raised from the lower surface of the scale, supported as upon arched pillars, by bundles of fibres, proceeding from the previously formed layer. This formation of the radiating fibres, prior to that of the horizontal layers through which they pass, is in accordance with what I have just described with reference to the homologous fibres at the margin of the scale. It is possible, that after they have been formed, the space enclosed within this series of expanded arches may have become filled up with the horizontal portions of each lamina: but this must still be regarded as a doubtful question. It is however obvious, that at the lateral margins, the corresponding fibres, which now become horizontal, project free into the open space, their investment with the upturned and reticulated portions of the central horizontal laminæ being apparently the result of a subsequent process.

The formation of the uppermost part of the scale is evidently accomplished by the successive additions of thin lamellæ to the surface, such laminæ being continuous with those which ascend from below: this continuity is well shown by fig. 22. As the vertical series of reticulated fibres approach the surface, their areolæ gradually become smaller and more circular and soon disappear altogether; at the same time the fibres spread out to form very thin lamellæ, which soon become calcified. The large canals, 20 *b* and 22 *b*, as well as the smaller tubes (22 *a*) entering from the surface, are formed, not by any prolongations of cells or cell-nuclei, for none such exist; but are the result of small apposite apertures left out in each successive layer as it is added to the preceding ones.

I have examined scales from several other examples of Ostraciont fish, and find that they are all constructed after one common type, varying only in the extent to which the process of calcification has affected the membranous tissues. In one small species the scale is almost wholly membranous. A thin superficial layer of kosmine, into which the tubes enter from the external surface, rests upon an equally thin homogeneous layer of calcareous substance, which has evidently been formed by the aggregation of minute granules, not unlike those of a Cycloid scale. Below these, near the margin, one single, very thin vertical lamina unites with an equally thin horizontal one, extending from side to side; whilst a third portion proceeds downwards from the junction of the former two, along the line 19 *d*—*i'*, to the lower edge of the scale.

The imperfect development of the calcareous elements of the latter scale contrasts strongly with that of the kosmine in some other portions of the fish. Three very large dermal spines project from its dermal covering, like those which give the name to *Ostracion cornutus*; one of these proceeds forwards from the upper anterior angle, immediately above and between the eyes, whilst the other two occupy the respective posterior inferior angles on each side of the tail. Throughout the greater portion of their extent they are cylindrical, and have their surfaces ornamented with numerous longitudinal ridges and intervening sulci. At their bases, where they are depressed vertically, the ridges terminate in rows of small tubercles, like those which stud the surface of the scale.

The internal structure of this spine is highly interesting, partly from the fact that it is merely one of the ordinary scales in which the superficial element is disproportionally developed and drawn out longitudinally, and partly because it explains the true nature of some well-known fossil ichthyolites. It contains a hollow pulp(?)-cavity, which exhibits no appearance of having been occupied by a cellular pulp, but is partly filled by a membrane composed of reticulated fibres, like those found in the ordinary scales. Around this is placed the calcareous portion of the spine, which wholly consists of kosmine, and includes the homologues both of the horizontal canals, 20 *b*, and of the more superficial tubuli, 20 *a*. The former of these are seen in the thicker portions of the spine, running parallel with the pulp(?)-cavity, and give off small kosmine tubes; the latter enter from the outer surface.

On making a transverse section, we obtain an exact fac-simile of the corresponding section of the fossil *Cœlorhynchus*, figured in my last memoir*. The superficial longitudinal ridges are seen to be the outer edges of long plates radiating from the centre of the spine to its circumference, separated by thin intervening layers of reticulated kosmine canals, which anastomose at their inner extremities with those which run parallel with the pulp(?)-cavity. With one or two unimportant exceptions, the description of the structure of the fossil *Cœlorhynchus* applies, even in its most minute details, to that of the recent spine. In the latter example, I have not seen the long semilunar canals represented by figs. 36 *g* and 37 *d**. There is also some difference in the construction of the bases of the two examples. *Cœlorhynchus* has always been regarded by ichthyologists as representing the true premaxillary bones of the fish to which the fossil originally belonged. This idea received some confirmation from the circumstance, that whilst at its apex it possessed a single central cavity, at its base this canal was not only divided into two by an intervening calcareous septum, but even the septum itself was duplex, consisting of two plates which were readily separated. Hence the opinion was adopted that the organism consisted of two separate bones, closely united, especially at the apices. I had always some difficulty in reconciling my observations with the above interpretation of the homology of this structure, especially since I could not detect a very clearly defined line of demarcation between the two supposed bones near their upper extremities. At length, however, I thought I had detected it, and figured it accordingly. Since then I have obtained more perfect sections of the fossil, through the kindness of Sir PHILIP EGERTON, and am now convinced that no such line does exist. The structure is one entire organism, only having a bifid base and a corresponding bifurcation of the central canal. I have hitherto seen no dermal spine exhibiting a kosmine structure, made up of two lateral elements, as is sometimes the case with the true *osseous* dorsal rays. *Cœlorhynchus* is, I am convinced, no exception to this general law, and from the light now thrown upon it by the study of the recent examples just described, I have no hesitation in arriving at the conclusion that it is a fossil example of a dermal spine of a large Ostraciont fish. The future discovery of the scales is a doubtful matter. It is possible, that like those of the specimen from which my spines were taken, they may have been principally membranous; still it is highly desirable that they should be sought for at the localities where the *Cœlorhynchus* is found. The new aspect which this fossil now assumes may render it desirable to change its generic name, since the present one conveys a false idea as to its true anatomical homology.

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* Philosophical Transactions, 1849, tab. 43. figs. 35, 36, 37.

Having completed the examination of as many modifications of scale-structures as fell within my reach, it became a question of considerable interest to ascertain what physiological relation could be traced between their structure and mode of development and that of the bones constituting the endoskeletons of this group of vertebrate animals. The overthrow of many of the old notions respecting the genesis of mammalian bones by Professor SHARPEY, has rendered it desirable that all forms of ossific growth should be subjected to a new and rigorous examination, in order to ascertain how far these collateral witnesses give support or otherwise to the highly philosophic views that he has enunciated.

I have employed the same method of investigation in this portion of the inquiry that I had previously applied to scale-structures. This especially consists in making sections, of each bone to be examined, in every direction that appeared likely to reveal any new feature of its structure, and examining the same bone, as far as was possible, in fishes of different ages. The result has satisfied me that Professor Sharpey's views not only receive the clearest possible confirmation from the study of the developing bones of osseous and cartilaginous fish, but that a large amount of additional light is thrown upon those views by such a study of the less advanced members of the vertebrate series.

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* *Ut supra.*

Dr. Sharpey has pointed out the fact that two distinct processes are put in operation during the growth of a mammalian bone. The first is the development of a cartilaginous matrix and the deposition of calcareous matter in its intercellular substance; the second is a deposition of similar matter in the fibrous membranes of the investing periosteum and perichondrium, prolongations of which, dipping into the interior of the organism, exhibit the same tendency to become calcified.

Both these processes exist amongst fishes, leading by their various modifications to very diversified results. In a great number of examples they are both seen in operation in the same bone. In some of these cases, the earlier cartilaginous bone-growth has been re-absorbed, and its place occupied by new bone developed in true fibrous membrane, in a manner that resembles, though it is not absolutely identical with, the process which Dr. Sharpey has shown to take place in mammalian bones. In other instances, the two structures, so distinct both in their origin and in their aspect, are developed side by side, and continue to retain their respective positions even in the most matured animals. This is especially the case in some fishes, which, like the Pike, permanently retain a large amount of cartilage in connection with their true osseous elements.

But in addition to these, there also exists a third group, apparently including the whole of the Sharks and Rays, in which only the first of these processes has gone on. The calcareous elements of their skeletons are nearly all constructed on the type of the temporary and transitional bone-growths developed in the intercellular substance of the cartilage along the line of ossification; only in these cartilaginous fishes, that which is transitional among the higher vertebrates, is here permanent. These endoskeletons are nearly all what may be termed *chondriform*. The two processes of growth being essentially different, it is desirable to apply to them distinct and intelligible names, and thus avoid the necessity of employing descriptive phrases every time that each one is referred to: the terms *chondriform* and *membraniform* appear sufficient for this purpose; the former being employed to designate those calcareous growths which are formed within the substance of the true cartilage, and the other being applied to the analogous growths which are formed by the calcification of laminæ of fibrous membrane. I would first direct attention to some examples of chondriform bone, as constituting the simplest type of true osseous structure.

Several writers have recorded the fact, that in the Plagiostomous fishes the cartilaginous skeleton is covered with "an osseous crust, which is composed of a great number of small plates or rod-like portions of bone united in the manner of mosaic work*." Mr. MILLAR has also described the structure somewhat more in detail, as forming the osseous covering of the cartilaginous skulls of the Sharks and Rays†; but neither of these authors has noticed the minute structure of these plates, or recognized their true physiological relationship to other forms of ichthyal and mammalian bone. Professor OWEN, in his admirable lectures, advances somewhat farther; he says, "in some species (of fishes) ossification commences at the periphery of the animal mould or basis, and is always limited to a thin outer crust of the bone, the rest remaining cartilaginous or gelatinous. In some of the higher cartilaginous fishes, for example, an osseous crust is formed upon the periphery of certain cartilages in the form of prisms, which contain oval calcigerous cells, but without conspicuous radiated tubes‡." Still even the accomplished author of the above passage does not appear to have observed the difference between these "calcigerous cells" and the canaliculated lacunæ of more highly organized bone; they are however perfectly distinct.

Fig. 28 exhibits a vertical section of the semicartilaginous column of the *Raia clavata*, or common Thornback. The section has been made *transversely*, crossing one of the vertebræ midway between its two concave extremities, the neural spine being removed; the neural canal (28 *a*) is surrounded by a layer of small calcareous plates, 28 *b*, and a corresponding series (28 *c*) covers the entire exterior of the structure, including not only the centrum and all the vertebral apophyses, but existing also along the lines of demarcation (28 *d*) separating the ossa intercalaria, which, in this group of fishes, often enter into the composition of the neural ring.

Fig. 29 represents a horizontal section of a portion of this osseous crust, taken from the lateral surface of the neural spine, and shows the way in which the small calcareous plates are fitted together. Each plate thus examined exhibits six or eight short, broad processes, 29 *a*, which meet corresponding ones projecting from the contiguous plates, 29 *b*. Sometimes these processes are not all arranged on one horizontal plane, but are on different levels, as at 29 *c*, where the upper pair is wanting, their deficiency being supplied by others deeper down. The uniform direction of these processes, modifying as they do that of the internal cells shortly to be noticed, give a stellate appearance to the surface of each plate; and their partial apposition through the projecting processes causes the existence of numerous small circular and oval interspaces, 29 *c* and *d*, which are occupied by a modified form of cartilage.

Fig. 30 represents one of these ossified plates still more highly magnified. The portions 30 *a*, *a'* are the projecting processes which have met corresponding ones from contiguous plates, whilst the intervening indentations (30 *b*) have contributed their share to the formation of the small oval interspaces seen in fig. 29. The surface of the section is seen to be crowded over with small round or oval cavities in the solid calcareous substance. These cavities are frequently linked together by narrow necks or irregular tubular canals, and in the projecting portions exhibit a strong tendency to assume a linear arrangement in groups which radiate from the centre, those of each group being more or less parallel to one another. In the calcareous inter-areolar substance, numerous concentric lines of growth are faintly visible, especially traversing the projecting processes at right angles to their direction.

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* MÜLLER's Elements of Physiology: translated by W. BALY, M.D., 2nd edit., 1840, p. 393.

† Footprints of the Creator, p. 41, fig. 7.

‡ Lectures on the Comparative Anatomy and Physiology of the Vertebrate Animals, Part I. p. 33.

Fig. 31 is a vertical section of one of these osseous plates, with a portion of the subjacent cartilage. At 31 *a* we perceive that the cartilage-cells present the ordinary ichthyal form, being gathered together in small detached groups. As we approach the inner surface of the osseous plate these groups begin to break up, and the cells re-arrange themselves in divergent lines (31 *b*), radiating from the centre of the calcareous structure. At the same time that their distribution is thus changed, each cell becomes more turgid, and exhibits more definite margins than before. The edges of the calcareous plate when thus intersected are seen to be thin, whilst its centre projects considerably into the cartilage; it presents the same array of internal cells that were seen in the horizontal section, fig. 30, but here their direction is changed, being nearly the same as that of the contiguous cartilage-cells. A careful examination of the line 31 *c*, where the two substances are in contact, makes it very evident that the calcareous matter is deposited, in the form of minute granules, in the intercellular spaces, which granules resemble, in their more essential features, those forming the calcareous laminæ of Cycloid scales, only being round instead of lenticular. They obviously increase in size by the addition of concentric layers, and by the coalescence of previously isolated granules. The small cavities correspond with what were originally cartilage-cells, but which, not having been filled up with the calcareous matter, have remained as small circular cavities in the solid structure. The point 31 *d* has evidently been the centre of ossification, and the new additions have been made both to the inner surface and to the peripheral margins of the plate; whilst the cavities in the centre of the structure have been arranged more or less vertically, the linear rows nearer the margin have been so deflected as to be almost parallel with the outer surface of the ossifying cartilage. This correspondence between the direction of the cavities and those of the contiguous cartilage-cells, which is important, as establishing the connection that exists between them, is also seen on examining one of the small circular interosseous points of cartilage visible on the surface, 29 *d*. Fig. 32 represents one of these cavities, into the composition of which portions of three osseous plates have entered (32 *a*). The cartilage-cells are here arranged in three arched series, and the cartilage itself assumes a semi-fibrous aspect, the fibres running in the same direction as the cells, which again corresponds with that of the small cavities in the contiguous processes of the calcareous plates. When one of these plates is decalcified, the animal basis retains the contour of the original structure. It has wholly lost its cartilaginous aspect, but its inner surface merges in the true cartilage and is inseparable from it.

There can be no doubt that each of these osseous plates is formed on a plan which is identical with that already referred to in mammalian bones, as explained by Professor Sharpey. The same processes are exhibited in both instances and follow the same order: the altered arrangement of the cartilage-cells, the calcification of the intercellular substance, and the production of small cavities in the bone corresponding with the position of, and owing their existence to, the cartilage-cells, are phenomena common to the growing bone of the mammal and the plates covering the cartilages of the Ray. But whilst in the former case this type is only transitional, leading to the formation of a still higher and more complex series of structures, by which its place is permanently occupied, in the latter instance it is the permanent state. Its physiological condition remains the same in the matured individual as in the fœtus, being only affected by the increase of bulk; and it furnishes another example of that permanent arrest of an early process in the development of the higher animals, of which so many instances are now on record.

On turning from the surface to the interior of the vertebral column of the Thornback Ray, we find that a modified form of the same physiological condition exists. It is well known that in the interior of the soft vertebral column of many of the cartilaginous fish, there exists a chain of calcareous elements, representing a series of osseous vertebral centres, but which have not advanced to a complete state of development. In the Ray, each of these exhibits the two concave extremities, connected together by divergent plates*, whilst a continuous canal is left open through their centres, within which the chorda dorsalis is lodged. In fig. 28, the vertical section has divided this osseous centrum, midway between its two concave extremities, exposing the canal of the chorda (28 *e*), the calcareous ring by which it is surrounded (28 *f*), and the fine radiating laminæ which connect the two extremities together. Of the latter, one proceeds upwards (28 *g*) to form the floor of the neural canal, two pass upwards and outwards (28 *h*) towards the parapophyses, and the two lower ones, which are bifid externally, are directed downwards and outwards (28 *i*).

On examining these several elements of each centrum under a still higher magnifying power, we see that they have precisely the same internal structure as the external osseous plates, modified only by minor differences in the forms and distribution of the small cavities, dependent upon the relative portions of the centrum which they occupy. In that which immediately surrounds the canal of the chorda (28 *f*), they exist as flattened cells, arranged in concentric rows; but in the projecting plates, 28 *g*, *h*, *i*, they are spherical and are disposed in radiating lines directed from the centre towards the periphery.

On examining the condition of the cartilage near the line of junction with the bone, we find very similar appearances to those seen in fig. 31, only the direction of the rows of cells is altered, in accordance with that which they have assumed in the contiguous portions of the bone. In the deep sulci intervening between the osseous plates, the cartilage has assumed the fibrous aspect already noticed, the fibres being arranged in more or less regularly divergent radii, of which the canal of the chorda has been the converging point. The rows of turgid and isolated cells follow the direction of these semi-fibrous lines in the cartilage. The calcareous additions are made to the whole surface where the growing centrum is in contact with the cartilage, but owing to the radiating distribution of the cartilage-cells, such of them as are incorporated with the *sides* of the plates, 28 *g*, *h*, *i*, are arranged in rows nearly parallel with the line of increment, whilst the cells at their *peripheral margins* are arranged at right angles to that line. I have been particular respecting the relative positions of the cartilage-cells and the small cavities existing within the calcareous centrum, because we thus learn the important relationship which the one series of structures bears to the other.

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* See Mr. Millar's Footprints of the Creator, fig. 8 *b*, p. 43.

When a transverse vertical section of the same vertebra is made near one of its extremities, so as to cut off a ring of bone from the margin of one of the terminal cones, we find a new modification in the arrangement of the cells. As in the central portion immediately surrounding the chorda, they are arranged in concentric circles, in which the cells exhibit so strong a tendency to coalesce, as to produce in many instances elongated concentric tubes, alternating with intervening ribs of calcareous matter. By carefully noting the gradual transition from these tubular appearances to those portions of the structure where the cavities continue to be isolated and spherical, it is easy to see that the differences are merely the result of a modified arrangement of similar cells. On examining a thin superficial section, taken from the surface of one of the growing plates, 28 *h* and *i*, we perceive that the first deposition of the earthy matter takes place immediately around the inflated cartilage-cell, each one being surrounded by a granular calcareous fringe. These granules soon coalesce; and the irregular rings thus formed continue to receive additions to their exterior until their more salient and contiguous points coalesce. Small angular interspaces exist for a while, but in process of time these also become filled up; and thus the cells are reduced to the condition of mere cavities in a solid calcareous structure, in which latter, by a careful management of the light, numerous small concentric rings may be traced, surrounding the permanent cavities and marking the lines of growth.

These centra contain none of the cancelli or Haversian canals seen in the ordinary forms of bone; the conditions which lead to the formation of both the one and the other have obviously no existence here. Bearing in mind the physiological relationship of these tissues in the Ray to those of the higher mammals, this deficiency of the higher osseous elements will be readily understood. Another important fact also to be remembered is, that the small circular cells existing in these bones and dermal plates, are not the homologues of the canaliculated lacunæ, known as the corpuscles of Purkinje. The former exhibit none of the beautiful radiating lacunæ which are so characteristic of the latter objects. It is true, we have frequently a small tubular canal connecting two such cavities together, but these are very different from the beautiful stellate objects seen in the bones of an eel or the scales of a *Lepidosteus*. The fact is, that though analogous they are not homologous. They differ in their structure, and still more in their origin; and the neglect of these differences has contributed, in no small degree, to produce the amount of obscurity and confusion that has hitherto invested the history both of the corpuscles of Purkinje and the genesis of bone, an obscurity which Dr. Sharpey was the first to clear away.

Turning from the flat Plagiostomes to the Sharks, we find that their osseous structures are essentially the same as amongst the Rays, though presenting numerous minor modifications, both in their modes of development and in the forms which their osseous centra ultimately assume.

The common Picked Dogfish (*Spinax acanthias*, Cuv.) presents one of the simplest types, and is one which can be studied with facility owing to the readiness with which examples can be obtained in different stages of their growth. The small plates with which the surfaces of the cartilages are covered, are not above one-fifth or one-sixth the size of those seen in the Ray, and are consequently more numerous in the same area; in other respects they closely resemble them. Mr. Millar has already pointed out the fact that the ossified centrum of the vertebra of the Dogfish is shaped like a hour-glass*. It is in fact an osseous cylinder, constricted in its centre and surrounding the canal of the chorda. If a vertebra be taken from a very young Dog-fish, and a section of it be prepared in the direction of that of the Ray (fig. 28), viz. vertically, midway between the two concave extremities, we shall perceive that the canal of the chorda dorsalis is surrounded by a very narrow ring of bone. Between the inner surface of this ring and the fibrous membrane lining the canal, there exists a considerable interval which is occupied by cartilage, in which the cells are uniformly diffused, excepting in the immediate vicinity of the bone, where they exhibit a slight disposition to assume a concentric arrangement. External to the osseous ring is the great bulk of the cartilage forming the vertebra. In that portion of it which surrounds the bone, the cells are arranged with great regularity in lines running from the ring towards the periphery. In the more external portions this radiated disposition is less obvious. Nearly the whole of the peripheral portions are invested by a thin osseous film, consisting of the small plates already spoken of. Similar ones line the greater portion of the neural canal, but are absent from its upper part, both externally and internally. These two series of external and internal plates are connected by means of the canals which allow of the exit of the spinal nerves; they also being lined with similar plates. The floor of the neural canal is occupied by one plate of much larger size than the rest, whilst external to it, but within the canal, is a small mass of cartilage, so that this bone is invested with cartilage on both its surfaces. At the inferior border of the centrum, or what would constitute the roof of the hæmal canal of a typical vertebra, there is a similar enlarged plate of bone, also invested by cartilage on every side.

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* Footprints of the Creator, p. 43, fig. 8 *a*.

On preparing a similar section from a vertebra of an older fish, we find that the same general arrangements of the parts exist, only some of them are altered in their respective dimensions. The osseous ring has encroached upon the cartilages, both at its inner and outer surfaces. In the additions made to the former portion, the cavities in the bone are compressed and arranged concentrically. In the external additions they are spherical, and arranged in radii, corresponding with those of the uncalcified cartilage. The two large plates occupying the upper and lower surfaces of the centrum have also increased in thickness, by additions made to each of their individual surfaces. Their enlargement has been accompanied by a corresponding expansion of the portions of cartilage which are external to them, thus providing for their further development.

On making a vertical section of one of these vertebræ in the longitudinal direction, or at right angles to the last, we find that the cartilage-cells external to the osseous ring still display the same radiating disposition, the lines diverging as they approach the periphery. The arrangement of the small cavities in the cylindrical bone is also analogous. Those which form the surface of each concave articulating extremity are very large, and are arranged in rows which are nearly parallel with that surface, having been developed around the cartilage-cells with which the latter portion is lined. Those which, on the other hand, constitute the exterior of the constricted osseous cylinder, are considerably smaller, and towards its terminal margins become subcompressed. We now also find that the osseous plate, constituting the floor of the neural canal, extends across the entire vertebra, and that its anterior and posterior extremities blend with the contiguous margins of the osseous cylinder. It is in fact a rudimentary vertical plate, serving the same purpose as that of the Ray, fig. 28 *g*; only instead of being developed, as in that example, direct from the osseous cylinder surrounding the chorda, it is formed at a distance from it, being attached to it only by its anterior and posterior extremities, the central portions of each being separated from one another by a semicircular mass of cartilage. As the growth of the fish advances still further, this cartilage continues to be encroached upon both above and below. I have never yet met with an example in which it was completely obliterated and its place wholly occupied by bone, but in very large and old fish it is nearly so, the plate connecting the two concave extremities being there very thick, the result of successive additions made to both its surfaces. The preceding remarks also apply to the corresponding plate on the opposite inferior surface of the centrum, only it never becomes enlarged to anything like the same extent as the superior one.

It will be seen that whilst in these bones of the Dog-fish the process of ossification is essentially the same as in the Ray, it differs in one important particular. In the latter fish all the new growths are added to *one* surface only; in the former, the additions are made to *two*. We have seen this to be the case, not only with the osseous cylinder immediately surrounding the chorda, but also with the superior and inferior laminæ; and there also appear to be indications of two *lateral* laminæ, formed in the same way, immediately above the parapophyses. We shall shortly find that this is the first step in some important physiological changes.

In the vertebræ of the large *Carcharias vulgaris*, Cuv., so common in osteological collections, the two terminal cones are united by four transverse bony plates; the two lateral ones are very large, whilst the intermediate ones are much smaller. These plates, as Müller, Professor Owen and others have already pointed out, are separated by deep, subcompressed, conical cavities, corresponding with the positions of the neurapophyses and parapophyses. Besides these large plates, there projects into the intervening cartilages four smaller ones; consequently a transverse section of a dried vertebra made midway between the two terminal cones will present the appearance of fig. 33, Plate XXXI.

In this section, the four cavities (33 *a*) have been occupied by cartilage, whilst the entire shaded surface is composed of chondriform bone. It consists of an innumerable series of minute areolæ or cavities, which, when more highly magnified, present the appearance seen in fig. 34. Professor Owen describes the vertebræ of the Tope (*Galeus communis*), and most sharks possessing the nictitating eyelid, as having their external surface, as well as the terminal cones of the centrum, covered by a smooth osseous crust, except at the openings of the four cavities. In the present example, the bone is not merely a crust, but exists as four solid cones, the apices of which unite at the middle of the centrum, from whence also are given off the small thin intervening plates, 33 *c*. The whole of this structure has been formed in the same way as the corresponding portions of the vertebræ of the Ray and Dogfish. The areolæ (34 *a*) are large, irregularly oval, and more or less compressed. The intervening calcareous portions (34 *b*) are small in proportion to the size of the areolar cavities, especially when compared with the relative development of the same textures in the Ray, where the earthy element is so much more abundant. These calcareous septa in the *Carcharias* are rough and somewhat irregular in their distribution, with the exception of a few more definite rows which take their rise from the lateral margins of each cone, 33 *d*, and proceed towards their peripheries. These rows are probably the result of lateral additions made to the cones during their process of incrcment.

A vertical section of the same vertebra, made at right angles to the last, along the dotted line, fig. 33 *e e*, reveals a somewhat different arrangement of the areolæ. The contour of such a section, unmagnified, is seen in fig. 36. The central portion of each half (36 *a*) is occupied by areolæ, like those, of which a magnified representation is given in fig. 34; but at each concave articular margin (36 *b*) there is an external layer, having a somewhat different structure. Fig. 35 represents a small portion removed from 36 *a*, and highly magnified. At the extreme margin (35 *a*) the areolæ are arranged in oblique vertical lines, which successively run out at the border, as they approach the upper and lower surfaces in the two halves of the section. In this respect, as well as in their somewhat elongated contour, they exactly correspond with the same areolæ in the vertebræ of the common Dog-fish. Within these there exists a second series, 35 *b*, which occupy the greater part of the lightly-shaded margins in fig. 36. The latter areolæ are small, almost square, and arranged in curious undulating chains, which proceed from the central mass of spherical cavities towards the concave articular surfaces, the various rows being separated by rods of calcareous matter.

Not having been able to obtain the bones of *Carcharias* in a very young state, I cannot speak with absolute certainty as to the directions in which ossification has extended itself; I suspect, however, that it has combined the leading features of both the Ray and the Dog-fish; whilst, like the former, the greater portion of the new bone has been added to the exterior of the osseous cylinder, primarily formed round the chorda: there have also been some additions (35 *a*) made to its internal surface, especially at its two concave extremities, as in the case of the Dog-fish. The principal point about which I am in doubt, has reference to the way in which the four divergent osseous cones have been formed; whether they have been directly developed from the osseous cylinder, as in the Ray, or whether their ossification has commenced at the surface, and been developed internally, until the whole of the subjacent cartilage has been incorporated, and they have thus become united throughout with the inner cylinder. It is most probable that the former of these modes has been adopted; but the point can only be determined by an examination of the bones of some very young examples of the fish.

On turning from the vertebræ to the jaws of the same fish, we obtain results which substantially coincide with those obtained from the Ray and the Dog-fish. The cartilage of the jaw has long been known to be invested by a layer of vertically elongated calcareous prisms. Their structure closely corresponds with that of those covering the vertebral and cephalic cartilages of the Rays, only instead of being merely flattened plates, a rapid vertical development has caused them to be more elongated; but their internal areolæ are arranged in much the same way as those of the Thornback, and their formation has been preceded by a corresponding arrangement of the cartilage-cells, which their calcareous walls have invested. The jaws of *Cestracion* exhibit an identical structure.

The several bones which enter into the composition of the rostrum of the Saw-fish, are also largely composed of an aggregation of similar small calcareous prisms. An imperfect sketch of a portion of this structure is represented in my last memoir*. I had noticed the difference between its aspect and that of ordinary bone, but not having then been able to interpret its meaning, I spoke doubtfully as to its osseous character. There is however no doubt that the entire rostrum which supports the lateral teeth consists of two kinds of bone, covered over with a fibrous skin in which are implanted the numerous minute dermal teeth. The calcareous chondriform prisms or rods exhibit some peculiarities. Their *internal* extremities exactly resemble the whole structure of those existing in the jaws of *Cestracion* and *Carcharias*; but the outer half of each osseous plate is very different. In order to obtain so considerable a bulk of solid calcareous matter as is required to give the requisite strength to the rostrum of the Saw-fish, nature has slightly modified her plan, but without abandoning the type prevailing amongst the other Plagiostomes; she has accomplished the object by adding largely to the length of each of these calcareous prisms; and where several of them proceed inwards from different sides of an angular cartilage and meet near its centre, they are twisted about in a peculiar manner, so as to fit in between one another, and thus increase the solidity of the structure.

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* Philosophical Transactions, Part II. 1849, fig. 34 *a*.

It is evident that each of these prisms in the Saw-fish consists, when divided vertically, of two distinct portions, an internal and an external one. At its rounded internal extremity, the areolæ are usually arranged in a fan-like semicircle of radiating lines; the same series is prolonged outwards like a hollow cone, which invests the inner half of the structure, and in which the cavities are arranged at right angles to its longer axis. The centre of this portion is occupied by a cone of a different structure, containing cells differently arranged. The external half of the bone corresponds with the central cones. It is also full of cavities, but they are much less spherical, and in the transverse section form an irregular network. They appear to have been left by the imperfect coalescence of elongated botryoidal rods, of which this part of the structure consists. Each half of these prisms has obviously been formed in a different way from the other. Instead of the primary point of ossification having been at the outer extremity or base, as is certainly the case with those of the Ray, and apparently also of *Carcharias* and *Cestracion*, in the present example I believe it to have been in the middle of the prism at the apex of the central cone; and that whilst new additions have been made to the sides and inner extremity of each prism by calcification of the cartilage in the way already described, cognate additions have also been made to its base; but these latter growths, *which become continuous throughout the entire bone, and not subdivided into vertical prisms,* have not been produced by the calcification of ordinary cartilage. They consist of a congeries of elongated botryoidal rods separated by long irregular cavities, the appearance of which in the transverse section has been already referred to. Though these cavities owe their existence to the imperfect calcification of the soft tissues, they are different from the areolæ formed by the investment of the globular cartilage-cells, at the opposite extremity of the prism. This continuous external portion has evidently been developed in a modified form of fibro-cartilage in which the cells have been less obvious. In the case of the Dog-fish, where we found that both external and internal additions were made to many of the ossifying points, I have already noticed that the cartilage in which the external growths were effected, assumed a much more fibrous aspect than that which was more internal; its cells also are very much less conspicuous, though it is continuous with the true cartilage, and merely a modified form of it. The external portions of the rostral cartilages of *Pristis* have undergone some similar but more marked modification, producing the peculiar differences that exist at the opposite extremities of each of the calcareous prisms. *The external continuous layer is obviously a rudimentary form of membraniform bone.*

The existence of these peculiar plates and prisms of chondriform bone, which appear to distinguish the recent sharks and rays from other fishes, is of some importance in its practical application to geology. In my memoir already so often referred to, I pointed out the circumstance, that in connection with what had always been regarded as the skin of the fossil *Hybodus reticulatus* from the lias of Lyme Regis, there existed a deep-seated layer of calcareous granules, which appeared to have been formed within the membranous tissues of the skin*. The more extended examination of recent forms which I have since made, has given me reason to conclude that these granules have belonged to the surface of the cartilaginous skull. The disappearance of the membranous portion of the skin, and of the soft cartilage, during the process of fossilization, would cause the dermal teeth implanted in the former, and the thin layer of calcareous granules investing the surface of the latter, to come into contact, and be permanently preserved in that state of close contiguity; so that what, along with other observers, I had always regarded as a layer of true skin, appears to be a combination of the calcareous elements of both the skin and the skull. On examining portions of the jaw in which the teeth are planted, and which is certainly a part of the endoskeleton, I find that it consists of a congeries of granules which are identical with those just referred to. In the memoir, I pointed out the existence, in the interior of each granule, of numerous small brown points, as well as of concentric lines of growth; the former of these I thought might possibly be merely the result of mineralization; I have now however no doubt that they have once been true areolæ formed by cartilage-cells, and that both these characteristics are homologous with the similar features presented by fig. 30. Some of the areolæ appear to have been filled up with a yellowish substance, and are no longer to be distinguished from the rest of the structure, which now presents the same hue; but the others have become occupied by brown carbonaceous matter, and are still obvious. We thus learn that the same structural peculiarities which are exhibited by the skeletons of the recent sharks, have also existed in their fossil allies of the Liassic æra.

But we can recede even still further into the past and obtain the same results. In the coal-measures of Leeds and Manchester, there are occasionally found small lustrous fragments, composed of a congeries of minute resinous-looking granules. When thin sections of these objects are examined under the microscope, we find that they have an internal structure closely resembling that of *Hybodus reticulatus*. Similar concentric lines of growth exist in each granule, following the outline of the numerous projecting points with which its surface is studded; in the interior is seen a beautiful series of minute rings and concentric circles, which I believe to owe their appearance to the original areolæ; other traces of the former existence of these areolæ are preserved in the numerous brown semicrystalline points which are crowded together in the interior of some specimens. From the repeated conjunction of some of these fragments with the curious teeth of *Diplodus gibbosus,* I have been led to the conclusion that they have both belonged to one fish. On mentioning my idea to Sir Philip Egerton, I was glad to find that it accorded with the conclusion arrived at by our highest British authority in the field of fossil ichthyology.

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* Philosophical Transactions, *ut supra*, p. 466, fig. 33.

We are thus furnished with two very decided examples of bone in a fossil state, belonging to the chondriform type, which, as far as my investigations have been carried, appears to characterize the recent Plagiostomes. Many others will I have no doubt be eventually found to exist; fragments, however small, when submitted to a careful microscopic examination, may thus be distinguished from the bones of the true osseous fishes.

After having ascertained some of the leading features attending the structure and growth of chondriform bone when unaccompanied with that of any other type, I turned my attention to the same topics in connection with the bones of the osseous fishes. In this portion of the investigation, the inquirer is often tempted to draw general inferences from partial and limited data; a proceeding, which I have learnt from experience to be especially dangerous in ichthyological studies; I have so frequently been astonished to find that the results obtained were widely different from what I had anticipated, owing to the endless diversity of the modifications of the osseous structures of fishes. Still there are certain great groups, the individual members of which are constructed upon a common plan, and whose osteo-genesis is very similar. By submitting well-selected examples from each of these groups to a careful investigation, we may obtain a large amount of detailed information, and be enabled to deduce generalizations which will be found applicable to large numbers of the osseous fishes, without necessarily tracing the progress of every bone in each individual species.

On examining a large number of Cycloid and Ctenoid fishes, we find that whilst the bones of some are so wholly osseous that scarcely a trace of cartilage remains in connection with them, others again preserve a large amount of cartilage in connection with their skeletons to the latest period of their existence. The Pike may be taken as an example of the latter, and the Cod, Haddock, Perch, &c., as belonging to the former of these classes.

Selecting the Pike (*Esox lucius*, Linn.) as a special subject of investigation, I have examined one by one, nearly every bone entering into the composition of its skeleton; making numerous sections of each, not merely in one fish, but in as many examples at different stages of their growth as I could conveniently obtain. From this series of observations I have been enabled to satisfy myself, in nearly every instance, as to the relations which the various osseous and cartilaginous portions have borne to each other.

There exists in nearly all the bones of the Pike more or less of cartilage, which, whilst it is partly internal, invariably makes its appearance at some portion of the external surface of each bone, and especially at the articulating margins. Around this cartilage there is developed a film of chondriform bone, which in some cases attains a considerable thickness, and which is again invested with layers of membraniform bone, into the direct composition of which no true cartilage structure ever enters.

The relative positions of these two osseous tissues, as they exist in the Pike, will be best comprehended by commencing the inquiry with some of the bones which are the least complex in their form. The carpals and stylo-hyals will serve this purpose*.

Fig. 37 represents a longitudinal section of a carpal bone from a Pike weighing about four ounces. It chiefly consists of a cylindrical rod of cartilage, very much dilated at its two extremities. At each of the latter portions (37 *a*, *a*) the cartilage-cells exhibit the common ichthyal aspect, being arranged in groups, each of which appears to be the result of successive divisions of a primary cell; or rather perhaps of successive developments of cells within those previously existing, as amongst the vegetable Algæ, reminding us strongly of the similar groups seen in a *Palmella* or a *Hœmatococcus*. At each tumid extremity the cartilage is only invested by a perichondrium; towards the centre it becomes much constricted, and its cells assume a new arrangement. The groups break up and the individuals become re-arranged in interrupted rows, those of each extremity curving somewhat inwards; near the centre of the shaft (37 *b*) these cells are globular, turgid, and almost in immediate contact with one another. The central point (37 *c*) is occupied by a congeries of minute spherical calcareous granules, which have become so aggregated at the surface of the cartilage as to produce a solid calcareous tissue. These granules are obviously chondriform bone-growths in an early stage of development, and correspond very closely, both in structure and in arrangement, with what exist amongst the cartilaginous Plagiostomes. Besides this central production of chondriform bone, a thin cylindrical layer of the same substance (37 *d*, *d'*) invests the exterior of the cartilage as far as the points, fig. 37 *e* and *e'*. It consists of an aggregation of granules, which, though smaller, in other respects resemble those of the centre of the organism. They are seen to be developed in the intercellular portions of the cartilage, leaving large round open areolæ, each of which is occupied by a cartilage-cell; additions to this chondriform bone are made by the production of new calcareous granules at its inner surface, within the tissue of the cartilage.

Investing this combination of cartilage and chondriform bone, we have a second osseous cylinder (37 *d*), of a very different aspect and origin. It is composed of numerous parallel superimposed lamellæ, many of which may be traced over the entire length of the bone, the more external ones being successively longer than those

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[*] I may observe that throughout this memoir I have followed the definite and philosophical nomenclature of Professor Owen, as employed in his beautiful work on the Homologies of the Vertebrate Skeleton.

which they invest, and consequently extending further along the surface of the cartilaginous matrix. At fig. 37 *g* is a small tubular space, caused by a slight inflection of the lamellæ, and at 37 *g'* a large cavity has been produced in a similar way; in the latter instance, a narrow passage proceeds obliquely upwards and outwards, through the successive laminæ, to the surface. This portion of the bone increases in size by the addition of new layers to its external surface, such layers being the result of a constantly progressing calcification of the fibrous periosteum with which it is covered; whilst at each extremity of the membraniform osseous cylinder the extending calcification takes place in the perichondrium, which appears to be merely an extension of the periosteum around the two cartilaginous extremities of the bone. No lacunæ exist amongst the osseous layers.

The original matrix of this bone has obviously been a small, cylindrical cartilaginous rod, in which chondriform bone has been primarily developed as a superficial ring midway between the two extremities; a nearly connate layer of membraniform bone being formed by the calcification of a portion of the perichondrium. The two extremities have continued to be cartilaginous. The cells of the latter tissue have multiplied in the ordinary manner at these extremities, where the cartilage has increased both in length and thickness. As this primary process has advanced, the membraniform and chondriform bones have continued to increase, as already described. Whilst the two osseous tissues have been developed by independent processes of growth, they appear to maintain some peculiar relationship to one another: thus at the four points (fig. 37 *e*, *e'*) they terminate together; the external or intramembranous growth being but a very slight degree in advance of that formed within the cartilage.

The above description will apply with the utmost exactness to the stylo-hyal bone of the same fish; belonging to the same cylindrical class, it presents identical appearances. In the early state of the large cerato-hyal, precisely analogous details of structure and growth may be traced out; and even in the matured fish, where the osseous elements are highly developed, the expanded cartilages of the two articular extremities are connected by means of a small narrow rod of the same tissue which passes through the centre of the bone.

Before turning from the cylindrical to the flat bones, it is desirable to note the structure of one or two which present an intermediate character. The epitympanic will best serve our purpose; since whilst in its depressed central portion it is closely allied to the flat bones, it is furnished with three long cylindrical processes or condyles. In its early state, a narrow layer of cartilage passes completely through the centre of this peculiar bone. In the adult fish this cartilage only appears externally at the extremities of the three condyles, which articulate respectively with the prefrontal, mastoid and opercular bones. But conical prolongations of these terminal cartilages extend along the interiors of the condyles, in the direction of the centre of the bone; and in a very young fish these cartilages meet near the base of the external process, which connects the epitympanic with the upper extremity of the pre-opercular bone. As the young fish increases in size, the central portion of this cartilage becomes absorbed, and is replaced by large cancellated cavities which are subsequently filled with cells of adipose tissue.

Fig. 38 represents a vertical section of the extremity of the opercular condyle as it exists in a Pike of about 3 lbs. weight. All the essential phenomena which are seen in the carpal bone are repeated here, only in a still more obvious form. At 38 *a* the cartilage-cells are distributed in small detached groups. At 38 *b* their arrangement is altered; they are disposed in interrupted vertical rows, passing from side to side, at right angles to the ossifying surface; a disposition which maintains throughout that portion of the cartilage which is invested by bone. At 38 *c* there is a layer of chondriform bone, produced in the same way as that seen in the corresponding portions of the carpal; only here it is much more extensively developed than in that example. It exhibits an areolar structure, which resembles, in the closest possible manner, some of the forms existing amongst the exclusively chondriform bones of the Sharks and Rays. This tissue is surmounted by successive lamellæ of membraniform bone, 38 *d*, exhibiting various arrangements of Haversian canals, 38 *e*. Sometimes these canals exist as large cavities left between two contiguous lamellæ, being the result of their mutual divergent inflections, and resembling those seen in the scale of the Sturgeon and the *Holoptychius*. At others they are the result of apertures left in the successive lamellæ, which have not been developed at the points along which the canal was intended to pass. This especially applies to the long oblique canals which proceed from the interior towards the surface of the bone. The membraniform lamellæ (38 *d*) are obviously growths successively added to the exterior; they encroach more and more upon the perichondrium surrounding the extremity of the cartilage as each new addition is made, being usually a little in advance of the subjacent chondriform bone. The latter circumstance we have already observed in the stylo-hyal and carpal bones.

Fig. 39 represents a similar section of the proximal half of the opposite condyle (or that which articulates with the postfrontal) from a young Pike weighing about six ounces. At 39 *a* we have the usual internal cartilage. At 39 *b* there is a very thin layer of chondriform bone, surrounded by a much thicker cylinder of membraniform bone (39 *c*) composed as usual of numerous parallel lamellæ. The chondriform layer is very thin in this instance, as compared with that of fig. 38. I have observed that it appears to be developed with greater rapidity at the extremities of these processes than at their bases, though it exists at both points. Fig. 39 *d* is part of the base of the external process extending from the centre of the epitympanic towards the preopercular. It consists of variously inflected layers of membraniform bone, perforated by innumerable irregular Haversian canals, each of which has been formed in the way already described, by the omission of the portions of the successively added lamellæ, opposite the pre-existing orifices of the canals. The internal cartilage has not been extended into this process, the bone being wholly membraniform in its nature and origin. Internally the Haversian canals terminate in a large irregular cavity, 39 *e*, which occupies the centre of the bone. This has once been filled with cartilage, which, with its chondriform bone, has been removed by a process of absorption. The process is still going forward at the point 39 *f*, where the cartilage has become detached from the inner surface of the investing membraniform bone, leaving an intervening space which gradually diminishes in extent up to the point 39 *g*, where the cartilage and bone still retain their contiguity. The same process occasionally goes on in other parts of the structure. Thus at 39 *h* a small portion of the cartilage has become absorbed, and the interior of the cavity thus formed has been lined with a layer of membrane, in which calcification has produced a thin film of bone, thus forming a sort of cancellated cavity communicating with the Haversian canal, 39 *k*.

If we examine corresponding sections of this bone from individuals of different ages, we shall find that the inner extremity of the cartilage recedes further from the centre of the bone as the fish advances in age; the irregular cavity left by its absorption being then more or less filled with adipose tissue.

In the paroccipital, exoccipital, alisphenoid and parietal bones, we find that a still more considerable marginal development of the cartilages exists. These bones being in contact with others at nearly every part of their periphery instead of touching at a few salient condyles, their cartilages are not confined to the interiors of cylindrical processes, but form thickened margins round the bones. An extension of this marginal cartilage traverses the interior of the bone, separating the upper from the lower osseous portions; but notwithstanding this modification of the type, the essential process of growth in all these instances has been the same as in the previous examples; chondriform bone being produced at the two surfaces of the cartilage, and membraniform bone still more externally. Thus in young states the latter constitutes two independent unconnected layers, separated, even in the most central portions, by a very thin layer of the cartilage, which is found to increase rapidly in thickness as we approach the periphery. In the bones of matured individuals these two layers are more or less united by the production of cancellated cavities and canals, which pass from the one to the other through the intervening cartilage. In the first instance these have merely been open spaces, produced by the partial absorption of the cartilage; but they have soon become lined with a membrane, which, as in fig. 39 *i*, has been converted into bone by a calcification of its lamellæ, chondriform bone being produced at the same time in the contiguous cartilage. I have especially observed these secondary bone-growths to be developed in the centre of the parietals and alisphenoids.

In the supraoccipital, the modes of increment are the same as in the bones just described, only throughout the greater part of this bone there has existed a very marked difference in the development of the superior and inferior osseous layers. Whilst the former is of considerable thickness, the latter is very thin. This fact prepared me for the existence of a still more marked difference in the case of the frontal. The greater part of this bone consists of an expansion of the upper layer only. The lower layer is developed, but to a very small degree, and that chiefly in the central portions of the bone. In some parts of the periphery, the thin membraniform structure appears to rest, not upon its own proper cartilaginous matrix, but upon that of one of the contiguous subjacent bones.

It will not be necessary to pursue the details of this portion of the Pike's skeleton any further. The examples already given suffice to show that all the bones entering into the composition of its cranium, have been produced according to one common plan, which, with various minor modifications, is identical with that on which the less complex carpal bone was constructed. There are, however, some other examples requiring a more special notice.

In the very young Pike, a small cylindrical rod of cartilage extends through the dentary, from the symphysis of the lower jaw, to the angle where it receives the anterior extremity of the mandible, and which is even prolonged a considerable way across the inner surface of the latter bone. This small cartilaginous rod has been the primary matrix of the dentary. In older fish its anterior extremity appears to become absorbed, the cavity being occupied by secondary cancelli, containing adipose tissue. The rest of the bone has been of primary intra-membranous growth.

The premaxillary exhibits similar features. It contains a central oval rod of cartilage, around which are arranged the investing layers of membraniform bone. In the latter portions there are some large cavities, which appear to have been formed, not by absorption of the cartilage, but by inflections of the membranous lamellæ prior to their calcification. In the dental surface of this bone, as seen in a transverse vertical section, we observe a curious arrangement of the Haversian canals. Immediately beneath the base of each tooth, there exists a group of small anastomosing canals, scarcely distinguishable from those seen in the contiguous portion of the tooth itself, and into which they open. Bearing in mind the intra-membranous origin of this portion of the bone, the above fact has a significant bearing upon the origin of the teeth. The central laminæ of the premaxillary contain a remarkable series of very minute parallel canals or tubes, which pass obliquely through them.

The presphenoid and vomer exhibit a peculiarity of structure, which at first sight appears to distinguish them from the other bones which I have examined; but this difference is more apparent than real. A thick cartilage intervenes between the vomer and the nasal bone, and a prolongation of the same cartilage runs backwards along the upper surface of the presphenoid. When vertical sections are made of the latter of these bones, we find that it appears to be developed on the inferior surface of the cartilage. The new lamellæ, which are membraniform, are added partly to the inferior surface of those pre-existing, but chiefly to their superior one, where a thin space, apparently lined with membrane, separates the bone from the contiguous cartilage. The inferior surface of the latter has not only a broad longitudinal depression receiving the upper surface of the bone, but also a long narrow central groove, into which is fitted the thin osseous vertical plate, which contributes to the formation of the interorbital septum. Though this bone is everywhere in close connection with the cartilage and bears a definite relationship to it, the two are really separated by an appreciable intervening cavity, in which the new membraniform bone is chiefly produced. No chondriform bone is visible in the cartilage. The anterior extremity of the presphenoid in an advanced stage of its growth exhibits some similar appearances. I do not believe that the above has been the primary fœtal condition of these bones. It is probable that both the presphenoid and the vomer are but exogenous prolongations from the sphenoid, and that the primary centre of their osseous development has been in the interior of the latter bone, which has been developed in conformity with the plan followed in other parts of the skeleton. The presphenoid and vomer would thus be the result of an unsymmetrical development of the lower half of the osseous structure produced around the primary cartilaginous matrix. We shall obtain some additional light on this point from an examination of the same bone in some other species of fish.

In the palatine bone a thin film of cartilage extends through its interior, and appears externally between the two condyles which respectively articulate with the maxillary and prefrontal bones, where it is of considerable thickness. Throughout a great extent of the thin posterior squamous portion of the bone the cartilage does not exist, the superior and inferior series of membraniform lamellæ being in direct contact.

None of the topics suggested by ichthyotomy have been productive of more elaborate disquisitions and debates than the opercular bones. Whilst some authors have regarded them as constituting a part of the endoskeleton, others have referred them to the exoskeleton, and considered them as being enlarged and modified scales. The latter opinion, which is the one entertained by M. Agassiz, has been recently combated by Prof. Owen, who, from an examination of the operculars of the Carp and Goldfish, concluded that their development "is effected in precisely the same way as that of the parietal and frontal bones. The cells which regulate the intus-susception and deposition of the earthy particles, make their appearance in the primitive blastema, in successive concentric layers, according to the same law which presides over the concentric arrangements of the radiated cells around the medullary canals in the bones of the higher vertebrata*." The above description, based as it is upon the long-prevailing idea that the lacunæ of the Haversian canals amongst the vertebrata owed their existence *directly* to the cells of the cartilage, does not, of course, agree in its details with my own observations; but it is perfectly accurate in its general bearing upon the moot question as to the nature of the opercular bones. The scales of the Pike are formed in precisely the same way as all the cycloid scales previously described. The structure of the opercular is wholly different, but is closely accordant with that of the bones of the endoskeleton.

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* Lectures on Comparative Anatomy, vol. ii. p. 139.

Fig. 40 represents a vertical section of the articular portion of this bone, passing through the articulation towards the posterior inferior angle. The concave articular cavity is partly lined with a fibrous structure (40 *a*) and partly with true cartilage (40 *b*), the latter of these tissues being chiefly confined to the central and internal portions of the cavity. A thin film of chondriform bone (40 *c*, *c′*) exists in the cartilage along its line of junction with the osseous structure.

Within the interior of this thick extremity of the bone is a large irregular cavity (40 *d*), which is of considerable width near the articulation, but contracts to a narrow space as it approaches the more flattened portions of the bone. It is traversed by a few thin and irregular laminæ (40 *e*), and is bounded internally by others (40 *f*), all of which are composed of membraniform bone. Anteriorly, the latter terminate at an obtuse angle at the surface of the chondriform bone 40 *c′*; corresponding in this respect with the relative positions of the two tissues in the condyle of the epitympanic (fig. 38), and differing only in the case of the opercular bone in the less oblique manner in which they come into contact. Similar lamellæ exist in the upper part of the section (40 *g*) forming the outermost portions of the bone; only instead of terminating abruptly at the articular cavity, they bend downwards and inwards (40 *g′*), so that each additional growth not merely enlarges the area of the articulation, but adds to the thickness of its walls. No chondriform bone exists at this point, and the inflected lamellæ are in contact with a fibrous tissue (40 *a*), instead of with cartilage. In the thin squamous portions of the bone, all the three series of lamellæ, viz. the outer, middle and innermost, 40 *e*, *f* and *g*, are prolonged in parallel layers; those occupying the two free surfaces are extended as far as the several margins of the bone, whilst those which are internal appear to stop short of them, thus accounting for the cycloidal markings seen on the surface of the bone, which are really lines of growth. In the thicker portion of the structure, these membraniform lamellæ are penetrated by curiously-formed Haversian canals (40 *h*). These do not however extend far into its thinner portions. The latter appear to receive their supply of nutritive fluids through numerous minute branching tubuli, which enter the bone at right angles from both its surfaces. They bear a close resemblance to those which are so abundant in the scales of *Lepidosteus* and other allied fish, and to which I gave the name of Lepidine.

There can be little doubt but that the primary matrix upon which this interesting bone has been developed, has been the small portion of cartilage still existing at 40 *b*, but which, owing to the peculiar requirements of the articulation into which it enters, has never attained to any considerable size. Whether or not a prolongation from it once filled the large cavity 40 *d* is uncertain; for though not improbable, I have seen nothing enabling me to conclude that it has done so. The existence of the thin film of chondriform bone at *c*, *c′*, proves clearly that this is not merely a superadded articular cartilage, but a veritable part of the growing structure. The relations of the several parts shows that the genesis of this bone conforms, as to its type, with what we have seen in all the other portions of the endoskeleton, the arrangement of the various structural elements being modified in accordance with the peculiar form of the bone into which they enter. On the other hand, they separate it wholly from scale structures, in connection with which cartilage and chondriform bone are alike unknown. It is scarcely necessary to add, that no visible cells enter into the composition of the membraniform lamellæ of the opercular of the Pike, any more than into the other analogous osseous structures which have passed under review.

The only remaining element of the skeleton of the Pike requiring a special notice is the vertebra, the growth of which is highly interesting: whilst the principles which have regulated the construction of the other bones are still adhered to, they have been subjected to such modifications as were rendered necessary by the peculiar form of the bone, and the functions which it had to fulfil.

Fig. 41 represents a transverse section of one of these vertebræ, made at right angles to the spinal axis and midway between its two terminal cones. In the centre is a small cavity, 41 *a*, through which the remains of the chorda dorsalis have been prolonged, and which is surrounded by a very thin ring of membraniform bone; from this ring there radiate eight conical segments having different structures; four of these are osseous, alternating with the other four which are cartilaginous. One of the osseous segments (41 *b*) proceeds upwards, to form the floor of the neural canal. Two others, somewhat larger than the last, 41 *c*, *c*, pass upwards and outwards, whilst the remaining one, occupying above one-fourth of the area of the section, passes both downwards and outwards, constituting the most substantial part of the centrum. When the vertebra is entire, these osseous segments appear as longitudinal plates, passing from the one terminal cone to the other.

Each of these segments is composed of large and irregular cancelli of membraniform bone, the walls of which have a laminated structure; but towards the periphery the laminæ lose their irregular distribution, and form a series of small radiating marginal plates, 41 *e*, between which are numerous open spaces, allowing a free communication to exist between the exterior and interior of the bone. These plates do not exist along the middle of each segment, which is occupied by a deep excavation, especially large in the inferior segment, 41 *d'*. These excavations correspond with longitudinal grooves which run along the surface of the radiating plates.

The lamellæ entering into the composition of the osseous laminæ, or walls of the cancelli, usually follow the same direction as the exteriors of these laminæ. But in the marginal plates (41 *e*) they appear in the form of investing cones, arranged parallel to the external outline of each plate, and being evidently the result of successive growths added to its exterior. The space intervening between these osseous segments are occupied by four corresponding ones of cartilage, 41 *f*, *g*, but which are of more uniform size. Of these, the peripheral portions of the two uppermost correspond with the bases of the neurapophyses, 41 *h*, whilst the lower ones bear the same relation to the parapophyses, 41 *i*.

In the central convergent portions of each of these cartilaginous segments, there is a limited formation of chondriform bone (41 *k*) arranged around the canal of the chorda, and which must contribute materially to the strength of the bone by cementing together the thin internal borders of the wedge-shaped osseous segments. Internally, this chondriform bone is consolidated, presenting only the usual small cellular areolæ; but external to this more solid structure is a fringe, consisting of innumerable minute spherical granules of various sizes, and which obviously represent the early conditions of the same tissue. As in the case of the lenticular granules seen in the fibrous membranes of cycloid scales, these granules increase in size, partly by the addition of concentric calcareous layers applied to their exteriors, and partly by the amalgamation of detached granules, which are bound together by the addition of common concentric coverings. Thus the chondriform bone is constantly encroaching upon the inner extremities of the four cartilages, the cells of which are remarkably elongated and fusiform, and radiate outwards in irregular lines, their long axes being disposed in the same direction. No chondriform bone invests the sides of the four osseous segments. Near the periphery of each cartilaginous segment the cells are more spherical, but still detached from each other and not arranged in the ordinary ichthyal groups seen at a greater distance from ossifying surfaces. On examining the outer margin of each cartilage, at its junction with the apophysis with which it is surmounted, we perceive that here also the former is being encroached upon by the latter. Each apophysis (41 *h* and *i*) consists of large cancelli, formed by laminæ of membraniform bone, and appears to be produced in the way already described, when speaking of some of the cranial bones. An irregular cavity is formed by the shrinking or partial absorption of the cartilage, which is afterwards lined by a fibrous membrane. This membrane becomes subsequently calcified, a copious development of chondriform bone taking place at the same time within the contiguous cartilage; hence a considerable amount of the latter structure (41 *l*) fringes the growing bases of these apophyses. There is great beauty in the way in which the various elements of the structure thus preserve their needful adaptation to each other. The enlargement of the divergent osseous segments by peripheral additions of membraniform bone, produces a corresponding increase in the intervening areas; the more external cells of the cartilages by which the latter are occupied multiply consentaneously in the ordinary way. Though the apophyses are not in this instance anchylosed to the osseous centrum, but detached, it is still necessary, in order to obtain a degree of firmness, that the bases of the former should be immediately in contact with the radiating plates of the latter, and not merely perched upon the top of the terminal prolongation of the cartilage which always projects into their interior. As the superficial area of each cartilage is enlarged, a corresponding expansion of the growing base of each apophysis is produced, and the requisite adaptation of the one to the other is thus maintained.

The four portions of chondriform bone (41 *k*) grouped around the canal of the chorda, are apparently analogous to the central nucleus, seen in the centres of the carpal and stylo-hyal bones (37 *c*), having a similar structure and origin. In each case its *continued* development is independent of the immediate proximity of any progressing growth of membraniform bone. The chondriform bone fringing the growing cancelli of the apophyses, on the other hand, bears more relation to that seen in the enlarging condyles of the epitympanic (38 *c*) and in the centres of the parietals and alisphenoids. When the cartilage at the base of each apophysis is absorbed, to make way for new cancelli, the contained granules of chondriform bone must necessarily disappear along with it.

We thus see, that, notwithstanding the great difference existing between the complex form of a Pike's vertebra and its more simply constructed carpal bone, the two are developed according to a common plan. Whilst the distinction between chondriform and membraniform bone is maintained in both cases, the two tissues invariably bear the same relation to each other.

Before leaving this portion of the subject, the close resemblance between the general direction of the divergent segments of *membraniform* bone in the vertebra of the Pike, fig. 41, and those of *chondriform* bone in the corresponding portion of the Thornback Ray, fig. 28, deserves a passing notice. The chief difference arises from the circumstance, that, whilst in the latter the two inferior plates (28 *i*) are separated by an intervening prolongation of cartilage, in the former (41 *d*) they have been united from the first. The substitution of the one kind of bone for the other in the two cases is an interesting fact.

After having thus acquainted myself with the structure and growth of the bones of the Pike, I pursued the same plan in reference to the bones of a number of other osseous fish, into the permanent composition of whose skeletons a much smaller amount of cartilage enters.

In the skeleton of the Perch (*Perca fluviatilis*, Linn.), I found that nearly all the bones, excepting the vertebræ, exhibited similar conditions to those existing in the Pike, modified only by the greater extent to which the cancelli have encroached upon the respective cartilages. The epitympanic bone taken from each of these fish presents a good illustration of the difference between them; on viewing their external aspect, the two bones appear to be very similar; but on making vertical sections of that of the Perch, we find that instead of the terminal cartilage being prolonged through the interior of each condyle, and almost reaching the centre of the bone, as in the case of the Pike, it only exhibits at its proximal part a very obtuse conical termination, penetrating but a little way into the concave extremity of the osseous portion of the condyle; its ossifying surface however still presents the peculiar film of chondriform bone. The remainder of the interior of the condyle consists of numerous membraniform cancelli, formed by successive encroachments upon the cartilage; whilst the external cylinder, also membraniform, has been produced in precisely the same way as the corresponding portion of the epitympanic of the Pike, fig. 38 *d*. The petrorsals, alisphenoids and other bones of the cranium also correspond in their mode of growth with the same bones in that example; only, in accordance with what has just been remarked, the cartilage in the centre of each bone has been more or less absorbed, and only exists permanently as an irregular external ring, separating the peripheries of the two osseous layers; being thick at its margin and becoming thinner as we approach the centre of the bone. The cancelli of the latter portion appear to have been formed as before.

The dentary bone also exhibits a cylindrical rod of cartilage projecting from its posterior angle, and extending across the inner surface of the mandible. The vomer and presphenoid are developed upon the under surface of the interorbital and nasal cartilage; only the projecting osseous lamina, contributing to the formation of the interorbital septum (which is almost rendered complete by a thin upward expansion of the cartilage), is still larger than in the Pike. In fact it may be briefly stated, that, with one exception, the processes of growth are the same in the Pike and in the Perch, only modified in the latter fish by the greater extent to which the osseous tissue has displaced the cartilaginous.

The exception to which I here refer is the vertebra. This bone is wholly osseous. No cartilaginous segments enter into its composition, and the various apophyses are firmly anchylosed to the bone. I have not been able to obtain any evidence indicating that cartilage has ever entered into its structure. It appears probable, that in the first instance an osseous ring has been developed in the membrane surrounding the chorda dorsalis, and that the sole way in which its subsequent growth has been effected, has been by peripheral additions of the same kind of bone, variously arranged.

The same peculiarities exist in the vertebræ of the Common Plaice (*Platessa vulgaris*, Flem.). I find no trace of cartilage in connection with them, even in the youngest examples which I have been able to obtain. Numerous irregular longitudinally disposed plates radiate from the centre towards the periphery, and are connected at right angles by other smaller laminæ which bind them together. There is an attempt at the formation of four distinct segments like the osseous ones in fig. 41, and it is just possible that in a *very early* fœtal condition, cartilage may have existed in the intermediate spaces. The way in which the bones of the Pike appear permanently to typify the earlier stages of the osteo-genesis of many other fish, would lead us to suspect that such may have been the case. If so, the cartilage has wholly disappeared very early; since we soon find that these intervals are also traversed, like the rest of the vertebra, by a few transverse laminæ, which thus convert them into large cancelli occupied by fat-cells. In the Plaice, the parapophyses are certainly nothing more than prolongations of the radiating plates, and not formed from independent centres of ossification: I have some doubts whether the neurapophyses have not been produced in the same exogenous way.

In the vertebræ of the young Haddock (*Morrhua æglefinus*, Cuv.), we find the same peculiarities as in those of the Perch and Plaice, but the outlines of the deep lateral fissures in the vertical section are still more strongly defined than in those examples. They are however filled up in the same way as in the Plaice, by transverse laminæ of membraniform bone. If the osseous neurapophyses have ever been independent of the centrum, they have become united at an exceedingly early age, since many of the lamellæ which enter into their composition may be readily traced down into the interior of the centrum.

On making a vertical section through the vertebra of the Cod (*Morrhua vulgaris*, Cuv.), parallel with the spinal axis, we see very clearly that the growth of the two terminating articular cones, and that of the laminæ by which they are connected together, have proceeded consentaneously. The osseous substance of these cones forms two thick and well-defined margins in a section so prepared. At the first glance, each of these terminal tissues appears to have been formed by the addition of new laminæ to their external or articular surfaces. This appearance however is fallacious, and arises from the existence of a series of minute radiating nutrient tubes, which permeate this portion of the bone at right angles to the real lines of growth; in the vertico-longitudinal section the latter are really transverse, and parallel with its peripheral surfaces. Nothing is easier than to show that the lamellæ, of which the longitudinal plates consist, are also prolonged into these marginal cones, and that the latter have been developed entirely by the successive additions of concentric lamellæ to their peripheries. The whole vertebra thus resembles a succession of thin closely-fitted cylinders, placed one within another, each one being successively larger than that which it invests; only instead of these cylinders being entire throughout their whole length, they are so only at their two extremities; the intervening portions being alike flexed and excavated, so as to produce the less regular laminæ forming the cancelli occupying the interior of the vertebra. The edges of the cylinders thus superimposed constitute the concentric rings seen in the concave articular extremities of each of these bones.

I am unable to see how this structure and mode of growth can be reconciled with the idea of the terminal cones being separately developed from two independent osseous centres, as thought by Professor Owen*. Corresponding sections of the vertebræ of the Pike, Plaice, Haddock, Perch and other fish, all lead me to corresponding conclusions as to the way in which these portions of the bones have been formed, though none of my sections show it with the same degree of clearness as those of the Cod. The small nutrient tubes in the latter example have been formed in the same way as the Haversian canals in the other bones of the Pike, by the omission of apposite points from the substance of the successively added lamellæ, which, as already observed, these tubes penetrate at right angles to their plane.

I am well aware that these views respecting the development of many vertebræ and their apophyses from one common centre of ossification, will not escape opposition, controverting as they do the ideas of some of our most justly distinguished ichthyotomists. Still I am convinced that an unbiassed examination of sections carefully prepared from fishes of different ages, will fully corroborate the general accuracy of the preceding descriptions.

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* On the Archetype and Homologies of the Vertebrate Skeleton, p. 82.

The other bones of the Cod, Haddock and Plaice agree in all material points with those of the Perch. The radius, ulna and femur of the Haddock are all produced by the development of membraniform bone on the two surfaces of a thin cartilage; but their thin osseous lamellæ have projected far beyond the cartilaginous matrix, as in the case of the opercular bones, thus producing the thin squamous expansions which constitute so large a portion of their substance.

Whatever may be the variations either in the form of the bones or the position occupied by the cartilaginous matrix, some portion of the latter always makes its appearance at the surface of the former up to a comparatively advanced stage of growth. As far as my present observations have enabled me to judge, this appears to be an invariable rule. In some bones, such as the coracoids and premaxillaries, scarcely any trace of the original cartilage can be found. Still even in these, though they consist almost wholly of membraniform bone, a small aperture may usually be detected at some point, where either a small portion of cartilage is retained, or which conducts to cancelli filled with fat-cells, by which it has been permanently supplanted.

The structure of the presphenoid in the very young Haddock illustrates my remarks respecting the same bone in the Pike. A slender cylinder of cartilage runs along its interior and is surrounded by concentric lamellæ of membraniform bone. This investing osseous cylinder can be distinctly traced backward far beyond the posterior apex of the cartilage, even when the space left by the absorption of the latter tissue has become occupied by well-marked, secondary cancelli. As we proceed anteriorly, we find that the continuity of the cylinder becomes interrupted by a small fissure dividing its upper walls, through which an expansion of the internal cartilage escapes, forming the interorbital septum: this fissure gradually becomes wider as the contained cartilage increases in size, forming the expansion of the same tissue which rests upon the vomer; the anterior portion of the presphenoid being at length reduced to an unsymmetrical prolongation of the lower laminæ of the primary cylinder; a trace of its original cylindrical character being preserved in the shallow groove marking its upper surface, on which the superincumbent cartilage still rests. In this case I have little doubt that the primary cartilaginous matrix occupied the centre of the sphenoid bone, of which the presphenoid appears to be only a vegetative, exogenous prolongation.

None of the bones hitherto described contain anything homologous with the canaliculated lacunæ seen in human bone. In those of the Eel (*Anguilla acutirostris*, Yarrell), such lacunæ, of the peculiar quadrate type so prevalent amongst fishes, are abundant; consequently I turned to their examination with a considerable degree of interest, being anxious to see whether the presence of these structures in any degree altered the genesis of the bones. As far as I have been able to comprehend this process in the bones of the Eel, they appear to conform to the leading phenomena seen in those of the Perch and its allies. The condyles of the epitympanic, for example, exhibit a very similar distribution of the cartilage and the bone, both chondriform and membraniform, as in those of the Perch. The lacunæ in the membraniform lamellæ appear to be merely additional appendages to the structure, and in no way influenced by the relations between the bone and the cartilage. In the vertebræ of the same fish we see no trace of cartilage, and yet the lacunæ are abundant; their plane and that of their spreading canaliculi following the direction of the contiguous flexed lamellæ, between which they are grouped. It is manifest that they are mere spaces which were left open when these lamellæ were successively added to the various surfaces of the growing bone, and are perfectly distinct from the analogous, but not homologous, areolæ, seen where the chondriform bone has invested the superficial cartilage-cells in the ossifying surfaces of the same fish. I may remark, that in this example also the laminæ of the parapophyses and neurapophyses are evidently continuous with those passing into the interior of the centrum.

The only other fish which I propose to notice in the present memoir is the Salmon (*Salmo salar*, Linn.), the bones of which present a singularly anomalous structure. In their external contours they do not appear to differ materially from those of the other osseous fishes, with the exception that the ichthyotomist finds them very difficult to dissect and disarticulate, owing to the circumstance that there exists in connection with them a large amount of cartilaginous tissue of a tough leathery consistency.

On making a vertical section of a vertebra in the same direction as that of the Pike (fig. 41), we perceive that there is a similar arrangement of the osseous and cartilaginous segments. The osseous tissue is full of areolæ of various forms, resembling those of the chondriform bones of Plagiostomes. They vary in shape, being sometimes spherical and at others elongated and fusiform. Instead however of growing merely at their extremities, the osseous elements increase wherever they come into contact with the cartilage, the increase proceeding the most rapidly at the peripheral portions of the osseous segments or plates. Where the cartilage is in contact with the sides of these plates, it is converted into a very marked form of *fibro*-cartilage, the fibres being exceedingly distinct, running in radiating lines from the centre of the organism, and of course being parallel with the growing lateral surfaces of the plates or segments. This altered character of the cartilage is equally obvious where it invests the peripheries of the radiating plates, and in all cases the cartilage-cells are retained amongst its parallel fibres, though considerably altered in their form and appearance. At the internal angle of each cartilaginous segment and at the bases of the neurapophyses, there exists a small amount of chondriform bone of a character which more closely resembles that in the corresponding portions of the vertebra of the Pike. In the Salmon, its areolæ are larger in proportion to the amount of the solid calcareous substance with which they are surrounded.

All the other bones exhibit a similar process of development to those of the osseous fishes previously described, only in every instance the bone retains its areolar character, and the investing periosteum appears to have more the character of a fibro-cartilage than of a simple fibrous membrane. The ossifying surfaces exhibit a film of chondriform bone like that seen at the bases of the neurapophyses of the vertebra; whilst laminæ of bone, resembling that seen in the centrum, successively shoot into the cartilage, the intervening portions of which are absorbed as they advance leaving long parallel cancelli, abounding in fat-cells. It is obvious, that a slight difference exists between the chondriform bone contained in the cartilage at the extremities of these elongating laminæ and that of the laminæ themselves, as well as of the osseous cylinder in which they are contained: the latter tissues approximate more to the nature of true membraniform bone, and yet they cannot be regarded as such. As far as I am able to comprehend their curious structure, all the bones of the Salmon appear to be of a chondriform character; but whilst in some cases, where the bone is designed to be a temporary growth, the calcareous matter is deposited in the unaltered intercellular substance of cartilage, in others, where the bone is designed to be permanent, the cartilage is converted into a fibro-cartilage previous to calcification. At the same time that the bones are increasing at their extremities in the way already described, a prolongation of the same altered cartilage or fibro-cartilage, containing fusiform cells, and investing their exteriors as a periosteum, is increasing their thickness by successive external additions, in which, as in the other parts of the skeleton, the presence of cells in the fibro-cartilaginous matrix leads to the existence of corresponding areolæ in the bone.

During the examination of the other osseous fishes referred to in the preceding pages, the question frequently suggested itself to me as to whence the fibrous membrane which lined the cavities encroaching upon the cartilage is derived; is it an altered condition of the surface of the cartilage itself, or after the latter was partially absorbed did the cavity become lined with an entirely new structure, which calcification was subsequently to convert into membraniform bone? Whatever was the origin of the tissue, it appeared to be of the same character as the perichondrium and the periosteum. In endeavouring to trace a line of division between the cartilage and the perichondrium I usually failed; whilst at the bases of the neurapophyses of the Pike, where the external periosteum and the subjacent internal fibro-cartilage came into contact, there appeared to be a commingling of the two tissues, rather than a mere juxtaposition. Many of these circumstances combine to produce a conviction, that the cavities about to be transformed into cancelli were *not* lined by an entirely new membrane, but by one formed out of the fibrillated substance of the cartilage. So far as I comprehend the growth of the bones of the Salmon, they appear to countenance this opinion. We find that the cartilage, prior to its conversion into what in other allied fishes would become membraniform bone, assumes in a very marked manner a fibrous character, without entirely losing its characteristic cells. At the same time, the *external* growths, which in other allied osseous fishes consist of similar membraniform bone, here exhibit the same areolar structure as the plates of the vertebral centrum, whilst they are surrounded by a periosteum which preserves all the characteristics of a genuine fibro-cartilage. The same remark applies to the osseous laminæ which encroach upon the receding cartilage along the ossifying extremities of the bone, which laminæ are of course also formed in the fibro-cartilage. These circumstances leave little doubt upon my own mind, that in the case of the Salmon, the structure about to be calcified, whether lining a cancellus or existing as a periosteum, is merely a fibrillated modification of the primary cartilaginous matrix, and it becomes increasingly probable that the same is the case with the homologous portions of other osseous fishes. The subject is too important in its bearings upon some branches of physiological science to allow of rash or premature conclusions, and consequently I would throw out the above suggestions in a spirit of due caution, being well aware of the vast amount of detailed observations yet requisite before the general principle can be established.

This structure of the bones of the Salmon also teaches us, that though the differences between membraniform and chondriform bone are usually clear and well-marked, yet the extreme forms of each may be connected by inosculating links, which break down the artificial distinctions that our imperfect philosophy would set up. We have learnt the same lesson from the snout of the Saw-fish.

It will scarcely be necessary to prolong this memoir by recapitulating the various conclusions which the observations detailed in the preceding pages have enabled me to deduce, since they have been recorded as we proceeded with the details of the several topics. There are however two or three questions upon which the preceding inquiries have some bearing, and which require a passing notice.

We have already found that the non-cellular, fibrous membranes of Cycloid and Ctenoid scales, the fibro-cartilages of the Salmon and Saw-fish, and the true cartilages of various other fishes, appear to be calcified in one common way, viz. by the formation of small calcareous granules, which are not interposed between, but actually incorporated with, the several tissues in which they are developed. In many of the examples which I have recorded, these granules are so large as to be easily examined, whilst the degrees to which their size is capable of being increased by the external addition of calcareous atoms, which are not themselves discernible, vary in different tissues and species of organisms. Analogical reasoning renders it probable that the calcification of such tissues as human teeth and bones may have been accomplished in the same way; only through the agency of granules which rarely attain a sufficient size to become visible even under high magnifying powers.

Another still more important inquiry suggested by the growth of the various forms of kosmine, has reference to the relation which they sustain to true dentinal structures. We have seen that a great variety of kosmine tissues exist, which exhibit the closest resemblance to several of the modifications of dentine described by Professor Owen. Thus in the areolæ of the *Megalichthys,* the dermal teeth of the rostrum of the

Saw-fish and numerous other Plagiostomes, as well as of the scale of the Siluroid, we have what closely resembles ordinary dentine, if not its homologue. In the elaborate structures covering the scales and occupying the interior of the spines of *Ostracion* and of *Cœlorhynchus*, we have beautiful examples of osteo- and vaso-dentine. The tubes which enter from the external surface of the same structures, remind us again of the very similar tubes, which, as Mr. Tomes has demonstrated, penetrate in like manner the enamel of the teeth of most marsupial animals. The many varieties of kosmine which I already possess, leaves little doubt on my own mind that when we are as well acquainted with the numerous modifications of this tissue as we already are with those of dentine, it will be found that every variety of the latter has its representative amongst the former class of structures. When we remember the undoubted fact that all these forms of kosmine have been produced by the calcification, not of a cellular pulp, like that to which the growth of dentine has been attributed, but of successively added lamellæ of purely fibrous membrane, we are bound to admit the *possibility* that dentine *may* have been formed in the same way. So long as the old opinions respecting the direct influence of cells on the production of the Haversian systems of mammalian bones were recognized, nothing was more natural than to account for the growth of teeth by a similar process; especially since a cellular structure, to which to refer the process, was so conveniently at hand. But now that the growth of bone is almost universally regarded by intelligent physiologists in a different light, and bearing in mind that a series of tissues closely resembling dentine have been formed without the intervention of any pulp-cells, the question naturally suggests itself, whether the cells of the pulp have any direct connection with the calcification of a human tooth. I have already pointed out that the " Pulp-cavity" of the spine of *Ostracion*, the recent representative of the fossil *Cœlorhynchus*, is chiefly occupied by a reticular fibrous membrane, such as is seen in the scales of the same fish. The dermal defence bones of the common Picked Dog-fish (*Spinax acanthias*, Cuv.) contain a " pulp" of true cartilage, exactly like that with which the bone of the endoskeleton is associated. Both these tissues, existing in the interiors of structures which bear a very close resemblance to true teeth, are very different from the pulp-cells of a mammalian tooth.

There are some points in the structure of a mammalian tooth, which suggest a doubt as to the correctness of the pre-existing hypotheses.

In Dr. Muller's Physiology, a representation is given of the external portions of some of the dentinal tubes, from the incisor of a full-grown Horse (Dr. Baly's Translation, 2nd edition, p. 428, fig. 41), in which many of the lateral twigs of each tube terminate in well-defined lacunæ with numerous canaliculi; a dense series of similar lacunæ is also represented as existing at the extremities of the main tubes, immediately below the enamel. I have carefully examined this portion of the tooth, both in the Horse and Ox, and, with Professor Owen, I differ from the interpretation given by Dr. Muller. I am disposed to think that the dentinal portion immediately subjacent to the external enamel, consists of an aggregation of very minute spherical granules, similar to those existing in the Cycloid scales of fish, and still more closely resembling those seen in the *external* half of each osseous rod or prism in the rostrum of the Saw-fish. I am unable to detect any well-defined lacunæ, with regular radiating canaliculi, such as are represented by Dr. Muller. It appears to me, that owing to the incomplete coalescence of the minute granules, an irregular network of minute angular interspaces is left, varying in their size, and typically resembling those seen in some scales, and in the portion of the Saw-fish just referred to. From these small interspaces, the twigs of the dentine-tubes take their rise. The same granular aspect of the calcareous intertubular structure continues to be visible for some distance along the course of the tubes, but nearer the pulp-cavity the amalgamation of the granules has been so complete, excepting where the dentinal tubes have been left open, that all traces of what I have just described completely disappears. I suspect that this is the structure which caught the eye of Mr. Nasmyth, and led him, at the sixth meeting of the British Association, to declare that the intertubular portions of teeth were cellular.

In the fœtal condition of the tooth, according to Purkinje and Raschow, the pulp is surrounded by a membrane, between which and the pulp, these observers believe the formation of the dentine to be carried on. It may be worthy of inquiry whether the calcareous structure is not developed *in* rather than *beneath* this membrane; a continual growth of the latter at the pulp-surface, however thin and inappreciable, would supply all that was wanting to carry on the corresponding growth of the calcareous tissues of the tooth. But even should there be no evidence that this has been the case, and we are compelled to fall back upon the pulp itself as the matrix in which the calcifying process is carried on, it does not necessarily follow that the cells of the pulp are involved in the process. We have already pointed out the probability that the new membrane, lining the cavities produced by absorption of the cartilage in many fish, and designed to be ultimately converted into osseous cancelli, is probably nothing more than an altered condition of the intercellular portion of the cartilage. A similar state of things exists at the surface of the cartilage forming the pulp of the defence spines of the Picked Dog-fish, where some new lamellæ are successively added to the interior of the kosmine structure. This suggests a second subject for investigation, viz. whether the soft blastema, in which the cells, vessels and nerves of the tooth-pulp are distributed, may not undergo a similar change prior to the calcification of its outermost portions. Whatever may be ultimately proved to be the true rationale of this process, there is no question whatever, that the various peculiarities attending the growth and development of kosmine, indicate the propriety of a careful review of the evidence upon which the generally received hypotheses respecting the production of dentinal tissues are based.

Somewhat allied to the above subject is the collateral one respecting the true nature of what I have designated Haversian canals. The canals permeating the bones of various fishes, are usually very different in their aspect from those with which the name of Havers has been connected by the anthropotomists. Similar complicated concentric systems of osseous lamellæ, with their parallel arrangements of lacunæ, have a definite existence in the scales of *Megalichthys*, and it is easy to trace a series of links which connect the latter with the more simple canals existing in the bones of the Pike; a further transition from these to the similar passages seen in the scale of *Dactylopterus* (fig. 14 *a*, *b* and *c*), and in the ganoin of *Balistes* (fig. 13 *f*, *f'*), is equally easy. Much as the extreme forms differ, the whole appears to represent one homologous series.

Another moot question, which derives some light from the preceding observations, is that of the nature of the opercular bones. Reference has been already made to the conflicting views of Professor Owen and M. Agassiz on this point; the former gentleman regarding them as portions of the endoskeleton, whilst the latter considers them to be enlarged and modified scales belonging to the dermal exoskeleton. The distinctions between the structure and mode of growth of cycloid scales, and of opercular bones, are clear and obvious. The characters are wholly dissimilar; whilst the genesis of the latter appears to be invariably connected with a primary development of cartilage, we have not the least ground for supposing that this tissue is ever connected with the former of these structures. In the case of the *Macropoma Mantelli* from the chalk, the distinction is even still more obvious than usual, owing to the large development of beautiful lacunæ, which has taken place in the true osseous opercula, and which correspond exactly with those seen in other portions of the endoskeleton, whilst nothing resembling them occurs in the interior of the true dermal scales. The existence of small points of kosmine on the surface of the operculum, resembling those covering the scale, does not invalidate this conclusion, since we find that closely analogous structures occur within the mouths of many osseous fish, connected with bones which are unquestionably portions of the endoskeleton.

The time has not yet arrived when any attempt can be safely made to arrange the various processes of ossification existing in fishes, so as to enable us to deduce from them any general law. Why one kind of bone should exist in the Salmon and another in the Pike; why the membraniform osseous tissues of the Eel, the *Lepidosteus osseus* and the *Loricaria* should abound in lacunæ, whilst they are absent from the corresponding tissues of the Cod, the Haddock and the Perch; and why the same tissues in the *Lepidosteus* and the fossil *Saurocephalus* should have in addition a large number of narrow tubes which also occur in the scales of *Lepidosteus* and *Lepidotus**, whilst these appendages are absent from the vast majority of ichthyal bones, are questions which we are not yet able to decide. The degree to which these several types prevail amongst the various families of fish is yet to be ascertained, and nothing but widely-extended observations will obtain for us the necessary information. Still it is very desirable that we should possess accurate knowledge on these various topics, since it would not only be valuable in a physiological point of view, but also in its practical application to geology. We already obtain faint glimpses of the prevalence of some general law, through the operation of which a number of varied products appear to be developed out of one primitive blastema. Chondriform and membraniform bone, kosmine, dentine, ganoin, enamel, cartilage, fibro-cartilage and fibrous periosteum, appear to be mysteriously linked together, and to possess some community of nature which is not yet fully revealed. The present attempt to add to the existing stock of facts, has only shown to me how wide a field still remains unexplored, which field must be worked out before we can fully comprehend the laws regulating the osteo-genesis of fishes.

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* Philosophical Transactions, *ut supra*, tab. xl. figs. 2 *b* and 3 *a*.

In conclusion, I have again to acknowledge the kind assistance which I have received from Sir Philip de Malpas Grey Egerton, who has facilitated my investigations in many ways, especially in supplying me with specimens for examination, which I could not otherwise have obtained.

Description of the Plates.

PLATE XXVIII.

Fig. 1. Scale of a Ctenoid fish from the Bay of Dulse (Mexico). Nat. size.

Fig. 2. Vertical section of the same scale, made in the direction of the dotted line, fig. 1 *a b*. Magnified 5 diameters.

Fig. 3. Still more highly magnified view of a portion of fig. 2 from *a*. Magnified 80 diameters.

Fig. 4. Similarly enlarged view of a portion from fig. 2 *b*. Magnified 80 diameters.

Fig. 5. Horizontal section of the lower or membranous laminæ of the same scale. Magnified 70 diameters.

Fig. 6. Horizontal section of the middle layer of the same scale. Magnified 100 diameters.

Fig. 7. Superficial aspect of a small portion taken from fig. 1 *c*. Magnified 25 diameters.

Fig. 8. Corresponding view of a portion removed from fig. 1 *d*. Magnified 25 diameters.

Fig. 9. Vertical section of part of the anterior portion of the scale of a Carp, made parallel to the mesial line. Magnified 160 diameters.

Fig. 10. Horizontal section of the uppermost of the membranous laminæ of the scale of the Perch. *Inverted* and magnified 200 diameters.

Fig. 11. Vertical section of the posterior margin of the scale of the Perch. Magnified 75 diameters.

Fig. 12. Horizontal aspect of the corresponding portion of the same scale. Magnified 50 diameters.

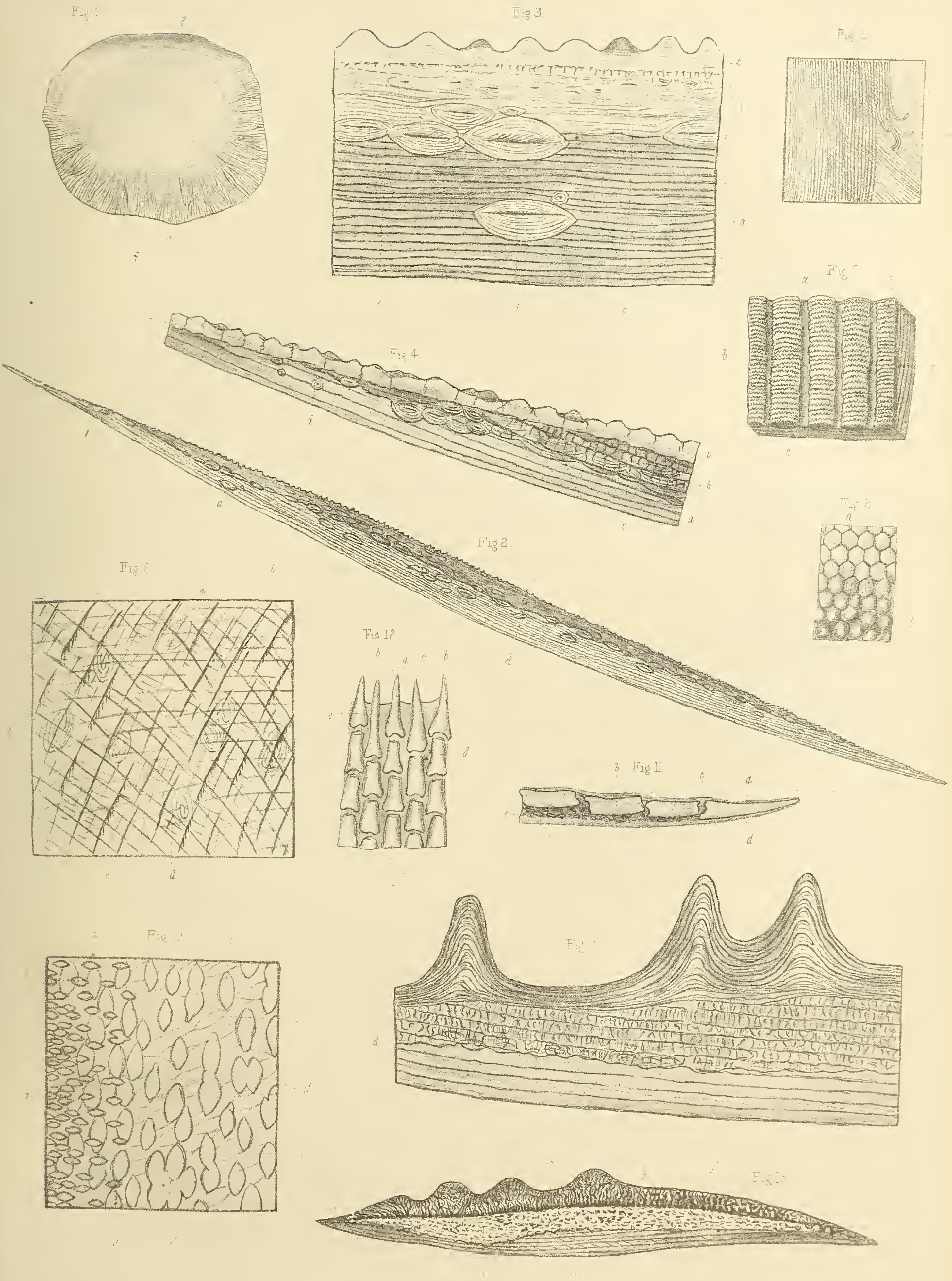
Fig 1
d
f
Fig 3
c
a
e
Fig 5
Fig 7
a
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Fig 2
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Fig 6
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Fig 12
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Fig 11
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Fig 13

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Fig. 14.

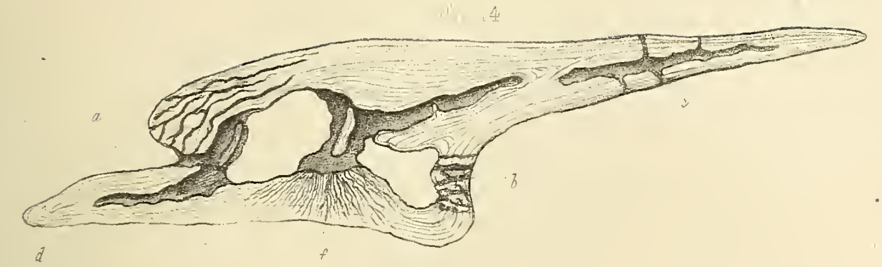


Fig 17

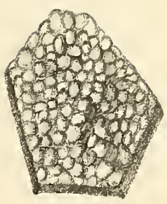
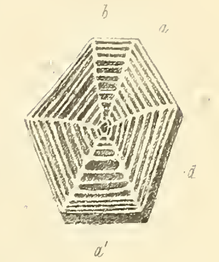


Fig 18



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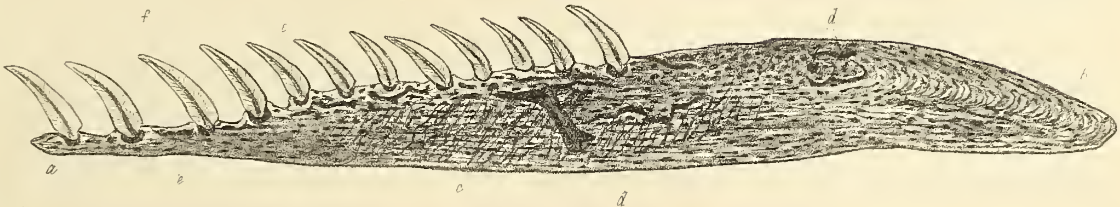

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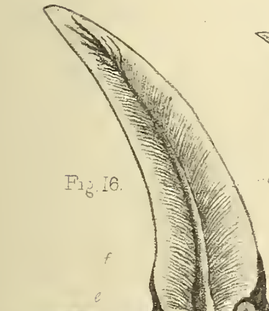

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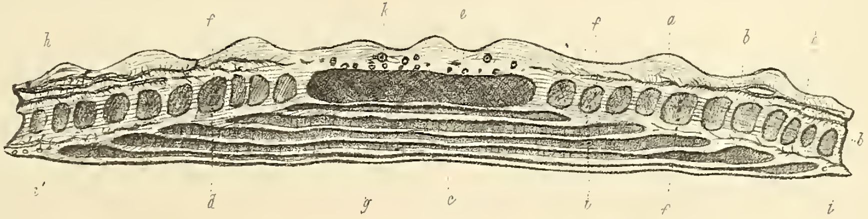

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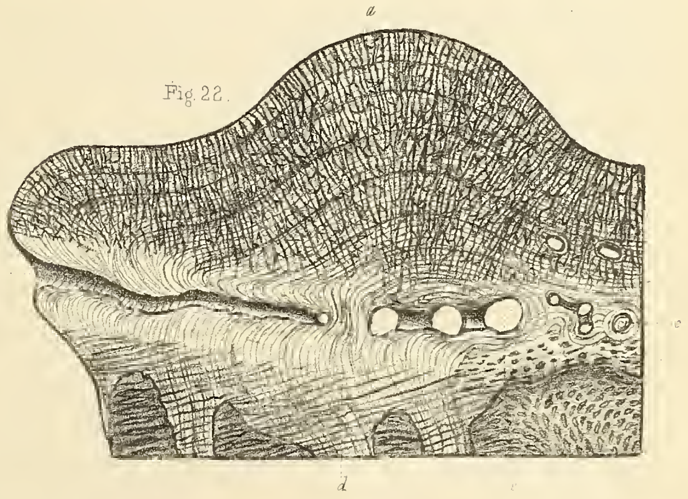

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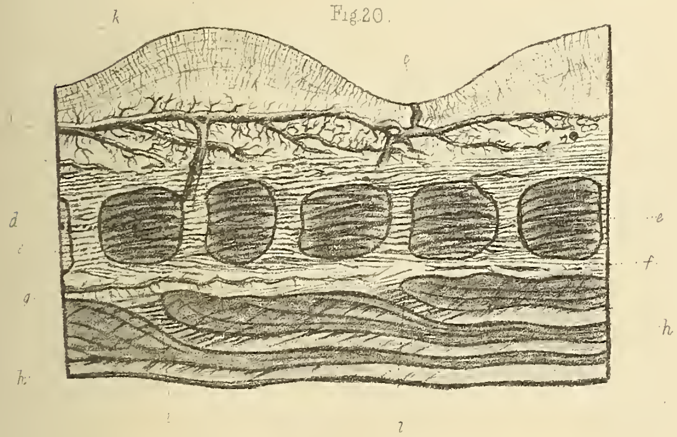

Fig 21

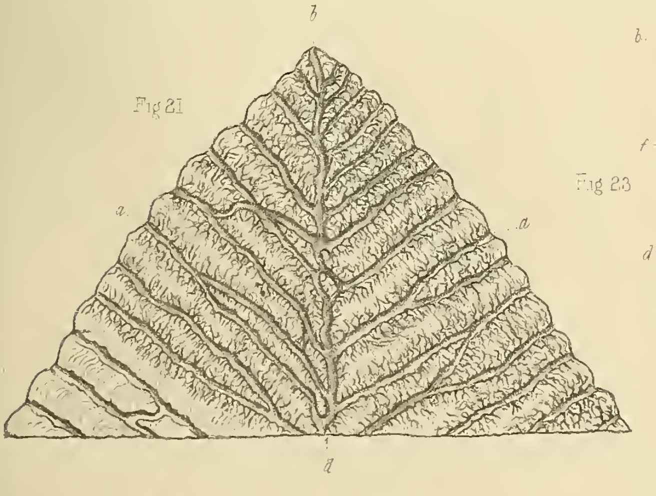

Fig 23

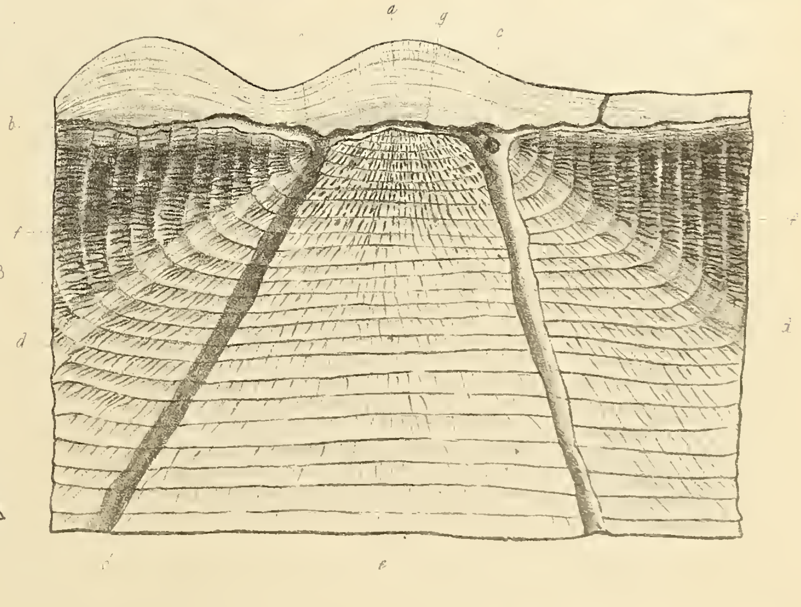

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Fig 25

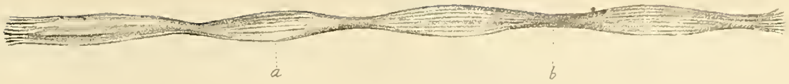


Fig. 24

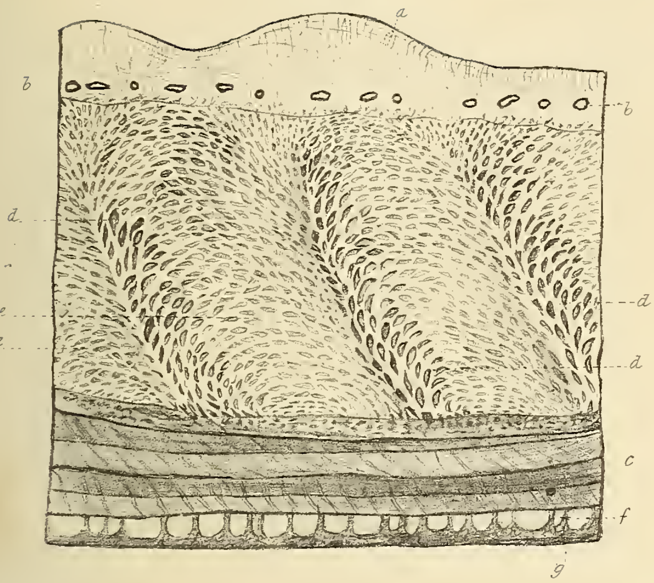
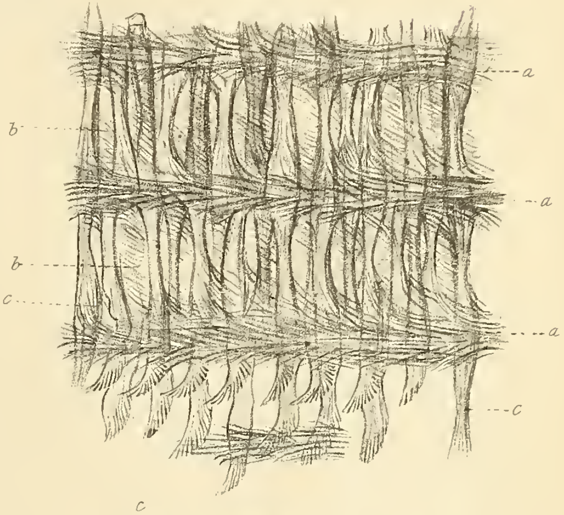


Fig. 26



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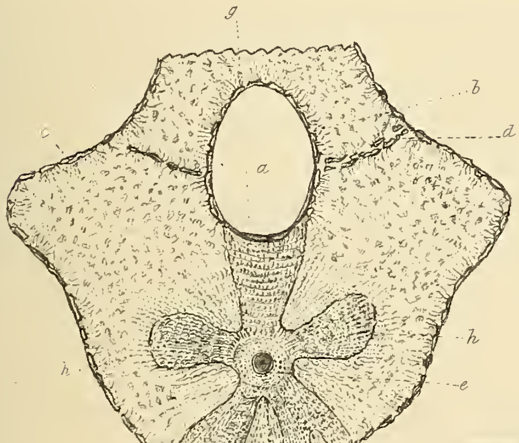

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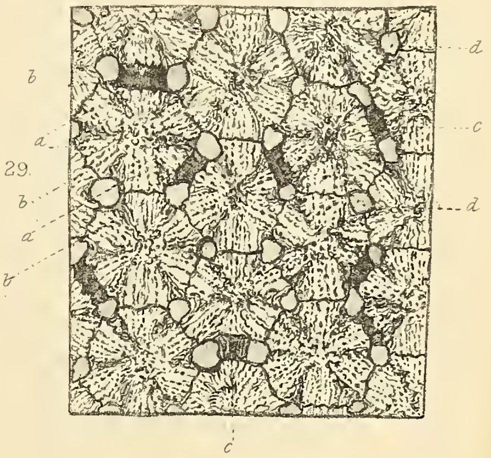

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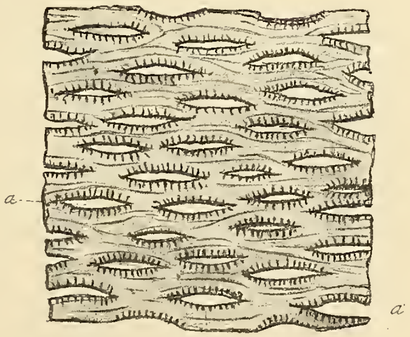

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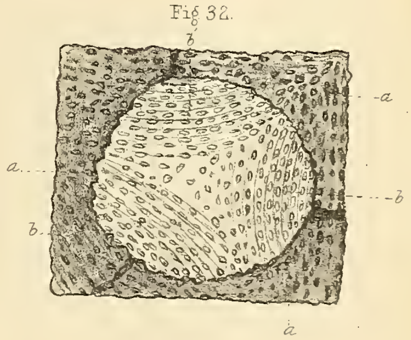

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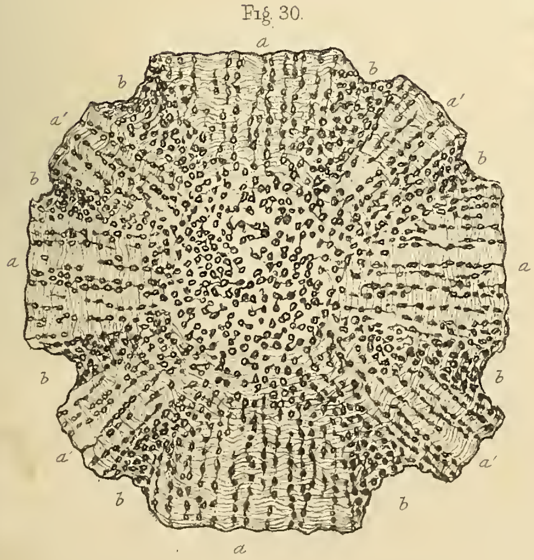

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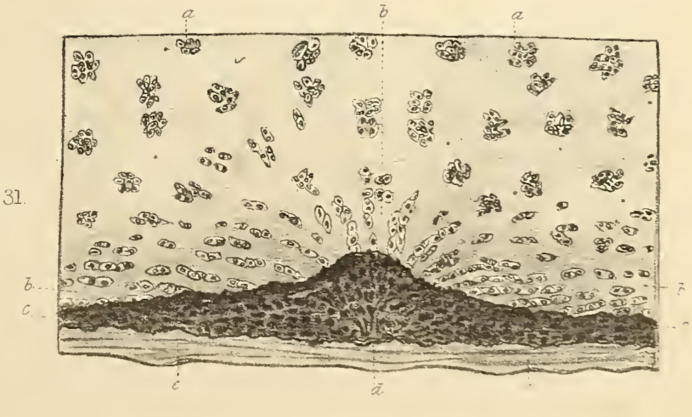

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Fig. 13. Vertical section of a scale of a species of *Balistes* (File-fish), made parallel to the lateral line. Magnified 18 diameters.

PLATE XXIX.

Fig. 14. Vertical section of a scale of the Flying Gurnard (*Dactylopterus*), parallel to the lateral line. Magnified 20 diameters.

Fig. 15. Vertical section of the scale of *Loricaria cataphracta*, Linn. (*L. setigera*, Lacepede). Magnified 14 diameters.

Fig. 16. One of the dermal teeth from the surface of the same scale. Magnified 65 diameters.

Fig. 17. Dermal plate from a species of *Ostracion*, superior surface. Magnified 3 diameters.

Fig. 18. Inferior surface of the same.

Fig. 19. Vertical section of the same along the dotted line, 18 *a a'*. Magnified 12 diameters.

Fig. 20. Portion of a similar section. Magnified 36 diameters.

Fig. 21. Horizontal section of one angle of the above scale, in the plane of the canals, fig. 19 *h* and 20 *b*. Magnified 12 diameters.

Fig. 22. Vertical section of the margin of a scale of another species of *Ostracion*. Magnified 60 diameters.

Fig. 23. Central portion of a vertico-transverse section of the last scale, subsequent to its decalcification, and made in the direction of the lines *a' b* in fig. 18. Magnified 40 diameters.

PLATE XXX.

Fig. 24. Vertical section of a portion of the same decalcified scale. Magnified 55 diameters. This section is made nearly at right angles to the last, and near one of its extremities.

Fig. 25. Bundle of fibres from the same decalcified scale. Magnified 250 diameters.

Fig. 26. Horizontal section of part of the same decalcified scale, a little inferior to the plane of fig. 21, and showing the fibrous bundles (fig. 25), and the reticular ones of fig. 24 *d* in their natural positions. Magnified 300 diameters.

Fig. 27. One of the calcareous septa, figs. 19 *b* and 20 *e*, after the animal matter has been removed by exposure to a boiling solution of caustic potass. Magnified 150 diameters.

Fig. 28. Vertical section of the vertebra of a Ray (*Raia clavata*), made at right angles to the spinal axis, midway between the two concave articular cones. Magnified 6 diameters.

Fig. 29. Horizontal section of the ossified surface of the neural spine of the same fish. Magnified 25 diameters.

Fig. 30. Enlarged view of one of the osseous plates of fig. 29. Magnified 160 diameters.

Fig. 31. Vertical section of one of the same osseous plates with its subjacent cartilage. Magnified 125 diameters.

Fig. 32. One of the small interspaces between the contiguous osseous plates, fig. 29 *d*. Magnified 130 diameters.

PLATE XXXI.

Fig. 33. Vertico-transverse section of one of the vertebræ of *Carcharias vulgaris*, midway between the two terminal cones. Natural size.

Fig. 34. Small portion of the internal structure of the same. Magnified 250 diameters.

Fig. 35. Small portion of the margin of fig. 36 *c*. Magnified 200 diameters.

Fig. 36. Vertical section of the vertebra of *Carcharias vulgaris*, parallel with the vertebral axis. Slightly enlarged.

Fig. 37. Longitudinal section of the carpal bone of a young Pike, (*Esox lucius*). Magnified 20 diameters.

Fig. 38. Longitudinal section of the extremity of the opercular condyle of the epitympanic bone of the Pike. Magnified 16 diameters.

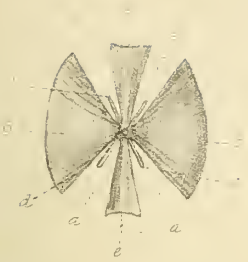
Fig. 39. Vertical section of the proximal half of one of the condyles of the same bone in a younger fish. Magnified 24 diameters.

Fig. 40. Vertical section of the articular extremity of the opercular bone of a Pike. Magnified 16 diameters.

Fig. 41. Vertical section across the centre of the vertebra of a Pike, at right angles to the vertebral axis. Magnified 8 diameters.

Since the preceding memoir was written, I have had the opportunity of examining the scales of the Eel, to which my attention was directed by my friend Dr. CARPENTER. I find that in them the calcareous portion consists *of a single layer, of detached calcareous granules*, which have not coalesced so as to form a continuous tissue. This is interesting, since it exhibits a rudimentary modification of the type, which becomes so much more fully developed in the scales of the higher osseous fishes.

Fig. 38.



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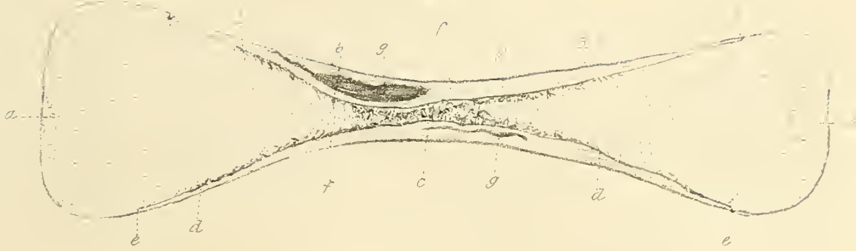

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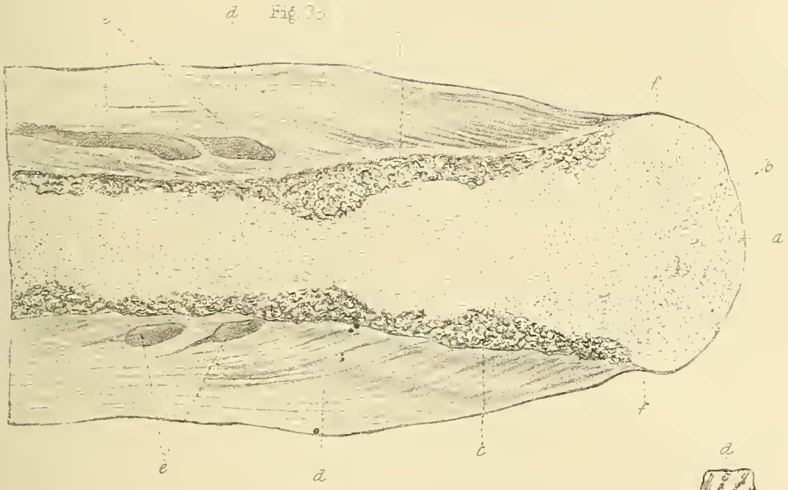

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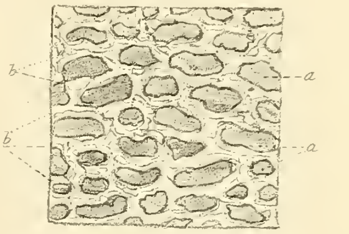

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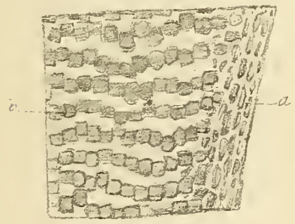

Fig. 39.

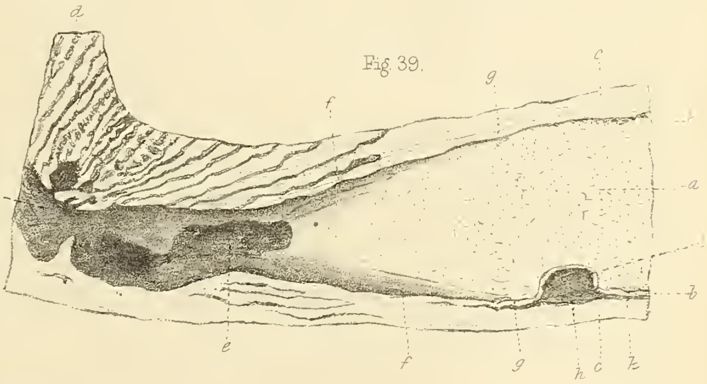

Fig. 40.

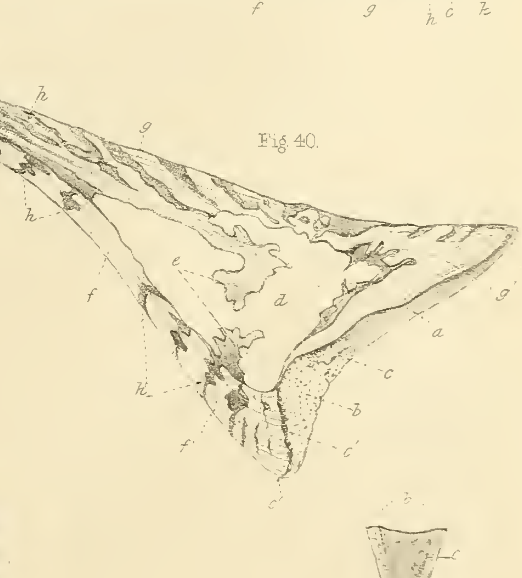

Fig. 41.

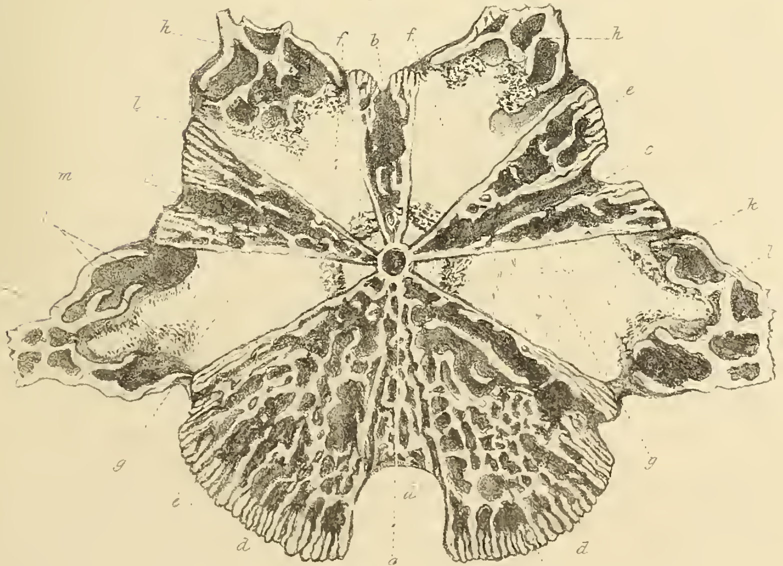

Fig. 36.

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XXX. *Report of further Observations upon the Tidal Streams of the North Sea and English Channel, with Remarks upon the Laws by which those Streams appear to be governed. By Captain* F. W. Beechey, *R.N., F.R.S. Communicated to Sir* Francis Beaufort, *K.C.B., Hydrographer, and presented to the Royal Society by* G. B. Airy, *Esq., F.R.S., and Astronomer Royal, &c.*

Received March 27,—Read May 15, 1851.

Sir, London, March 11th, 1851.

In pursuance of directions from the Lords Commissioners of the Admiralty that I should make further inquiry into the phenomena of the tidal streams of the Channel, I commenced a systematic investigation of the whole feature of tidal-streams throughout the strait which separates England from the Continent, and I have now the satisfaction to lay before you for their Lordships' information the result of these labours.

In order to prosecute this inquiry with as much advantage and as little delay as possible, I have combined with the information furnished by the vessel appropriated to this service as many observations from various authentic sources as were recommended by the known reputation of their authors.

Authorities consulted.

These consisted of various observations upon the streams of the English Channel and the North Sea by Captain Martin White, R.N., Captain Washington, R.N., Captain Hewitt, R.N., and Captain Bullock, R.N. Also by Monsieur Monnier, M. Beautems Beaupres, and by the Engineurs Hydrographiques, published in the 'Pilote Française.' To these have been added some by Mr. Græme Spence about the Scilly Islands, and a few by Captain Anderson, as given in the Philosophical Transactions; numerous observations along the shore by the Coast Guard, and a series of observations kept on board the light-vessels by order of the Trinity Board, which are particularly valuable as being made simultaneously, and, like those of Captain Washington, continued throughout several days at each station.

Method pursued in making the observations.

The method pursued in making the observations, was to anchor the vessel at each of the stations* for twelve hours and upwards, and to observe the direction of the tide, ebb and flood, every half-hour. The rate of the stream, in addition to the usual method by the common log, was detected by current logs, constructed for the purpose by Mr. Massey, and which registered feet; and that it might be ascertained whether the stream was confined to the surface or extended to the depth of a vessel's hull in the water, another of these logs was occasionally sunk 12 feet, and registered simultaneously with the one which was 2 feet beneath the surface.

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* See Chart of the Stations, Plate XXXII.

Method of making the observations.

The time of slack water, as well as the times of the cessation and commencement of the stream, were noted, as closely as such observations are capable of being made; and to render the times more certain, I have taken the mean interval between the time of the cessation of one stream and the time of the commencement of the next. The times of high water at Dover have been taken from the Admiralty Tide Tables, which were tested by observations made at Dover during some portion of the observations in the Channel, and the agreement being found sufficiently near to render a special register unnecessary, it was discontinued.

All the times of observation being referred to the *meridian of Dover*, and compared with corresponding times of high and low water at that place, tables of differences were obtained which gave *the interval between the time of slack water at each station, and the time of high water on the shore at Dover*, and also the direction and rate of the stream at each hour of the tide before and after the same standard. By this method of comparison observations made at various periods, and even in different years, were brought as nearly as possible to a simultaneous record.

To exhibit these results tables were drawn out, and twelve charts were constructed, showing the position of the stations and the direction of the stream at each hour of the tide at those places respectively, in order that the eye might at once detect the movement of the stream throughout both channels at any instant of time*.

In these charts the direction of the stream is indicated by arrows, which are connected by curved lines empirically drawn through them; these lines are continuous when the water is flowing towards Dover, and broken when running in the reverse direction. Lastly, all those tides which have a rotatory motion are indicated by spirals barbed in the direction in which they revolve.

Results.

All the observations having been subjected to this arrangement, some highly important results were obtained. Instead of these channels having, as has been hitherto supposed, a stream which turns progressively later as the tide advances up the strait, these observations have shown that the progressive changes of stream cease at a certain point near the mouth of the Channel, and that beyond that spot there is a tide peculiar to the Channel, and quite distinct from that of the seas on either side of it; so that there may be said to be two distinct streams on each side of the Strait of Dover,—the stream of the Ocean or outer stream, and the stream of the Channel, or that which is contained between the oceanic stream and the Strait of Dover. These streams are always running in contrary directions, and in the North Sea meet between the Texel and the estuary of Lynn; and in the English Channel between the Start and the Gulf of St. Malo.

Oceanic and Channel streams.

Mixed tides.

In the localities where these streams meet, the tide is ever varying its direction according as the strength of one stream prevails over that of the other; giving to the water a rotatory motion, and scarcely admitting of any interval of slack water; whilst in the space between these rotatory tides and the point of meeting of the tides in the Strait of Dover, the stream is free from all rotatory motion, and sets steadily throughout the tide in a direction *towards* Dover, while the water is *rising there* and *away* from it while it is *falling at* that place.

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* Eight of these charts only have been published.

Rotatory streams. TrueChannel stream.

I have designated the last-mentioned the "*true channel stream*," and its extent is, as nearly as it can be measured, 180 miles in either direction from the point of union of the tides in the Strait of Dover to the region of rotatory tides off Lynn, and off the Start and St. Malo.

Extent of the Channel stream.

As the true Channel streams are always running in opposite courses, there is necessarily a point where they meet and separate; and this occurs in the Strait of Dover. But *in this strait*, the stream, although it first obeys one tide and then the other, does not slack with the Channel streams, but is found to be still running at high and low water on the shore, at which times those streams are at rest, so that the Strait of Dover never has slack water throughout its whole extent at any time. I have in consequence called this an *intermediate* tide.

Meet in the Strait of Dover.

Intermediate tide.

The limits of neither of these streams appear to be stationary, but *range to and fro as the tide rises and falls at Dover*, travelling to the *eastward* on *both* tides, and at high and low water suddenly shifting sixty miles to the westward to recommence their easterly courses with the next tide; and although so far apart, they possess the remarkable peculiarity of shifting together; so that the Channel streams preserve, as nearly as possible, the same relative dimensions.

Place of meeting of the tides changes with advance of the tide.

In the Strait of Dover this line of meeting and of separation oscillates between Beachy Head and the North Foreland, a distance of about sixty miles. When the water on the shore at Dover begins *to fall*, a *separation* of the Channel streams begins off Beachy Head. As the fall continues, this line creeps *to the eastward*. At two hours after high water it has reached Hastings; at three hours Rye; and thus it travels on until at low water, by the shore, it has arrived nearly at the North Foreland on one side of the strait, and at Dunkirk on the other. At this time the *Channel streams* on both sides slack, but in that portion which I call *the intermediate stream* in the Strait of Dover the water is still running to the westward; and when the new *Channel* streams make as the water rises on the shore, this *intermediate* portion is found to unite with, or to oppose one or the other of these streams, according as it was before the reverse; so that, as before mentioned, the line of meeting at low water appears off Beachy Head to recommence its easterly course. This *intermediate* stream forms a remarkable feature in the tidal system of the Channel; it is well established, as the line of meeting and of separation occupies a very limited space, and it seems to be entirely due to the contracted form of the Channel in this immediate locality, preventing the free escape of the water.

Peculiarity of the stream in Dover Strait.

Captain Bullock, in order to test the point of separation, anchored two vessels a mile apart between Beachy Head and Dungeness, and found both vessels at the same moment to ride with their heads in opposite directions, in obedience to the streams which were then running opposite ways.

Channel stream.

The *Channel stream*, which I have described as running between the intermediate stream and the rotatory or mixed streams at the outer extremities of the Channel, pursues a steady course along the main trunk of the strait, slacking only towards high and low water at Dover, when it is preparing to invert its course; and contrary to the generally received opinion of *a progressive slack water* in a strait having *a progressive establishment*, this stream has the peculiarity of slacking throughout its whole extent at *nearly the same time*, and this time, as was anticipated in my former paper, corresponds nearly with the time of high and low water on the shore at Dover, the site of the combined wave and of the *virtual head of the tide*.

Stream slacks at nearly the same time throughout.

Such is a general description of the phenomena of the streams of the English Channel and the North Sea; and I shall now endeavour to describe more in detail the several peculiarities of these features, and to remove various erroneous impressions which at present exist as to the rotatory motion of our tides, the direction in which the streams turn, and also as to the time of the stream attaining its maximum rate, &c., and then to lay before you such data as it appears to me will help to explain the cause of the tidal streams of these channels differing from those peculiar to ordinary tide-waves.

Simultaneous turn of the stream.

As the simultaneous turn of the stream is a point of considerable interest, I may be permitted to dwell a few minutes upon the data from which it has been derived. But I wish it to be clearly understood, that minute accuracy on such a point is scarcely possible, and could only be obtained by a long series of simultaneous observations at the extremities of the tide-wave; for the period of slack water is almost always spread over an interval of half an hour, and not unfrequently at the neaps, of an hour and upwards; and moreover winds are found to prolong the stream in the Channel according to the direction in which they blow. In estimating the time of slack water therefore from the observations, we must not expect a very close agreement*.

Time of high water at Dover, and the time of the turn of the stream compared.

It will be seen, on a very cursory inspection of the Charts which accompany this paper, that for a period of six hours after high water at Dover, and for five hours before that time, the stream maintains a steady direction from and towards Dover, so that any delay which may exist between the change of the stream and the time of high water is shown by these charts alone to be confined within very narrow limits, but a still closer agreement will be found on referring to the observations themselves*; especially if we take those which were made on board the light-vessels at a distance from the shore, which are particularly valuable from the circumstance of their being spread over intervals of several days at each station.

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* The times of observed slack water at the stations marked in the Plans, as compared with the times of corresponding high waters at Dover, as shown by the tide tables, together with all other particulars relating to these observations, will be found entered in a book which accompanies this report, since deposited at the Hydrographic Office of the Admiralty.

Comparison continued.

Referring then to these observations, and taking them in the order in which the light-vessels are placed with respect to the progress of the tide-wave, we shall have the intervals between the turn of the stream at those places, and the time of high water at Dover (the standard), as follows :—

At the Newarp L.V., the stream is slack twenty-two minutes before Dover.

At the Cockle L.V., the stream is slack at the same time as Dover.

At the Stanford L.V., the stream is slack nine minutes before Dover.

At two stations nearer Dover, the stream is slack twenty-four minutes after.

At the Shipwash L.V., the stream is slack twenty-four minutes after.

At the Galloper L.V., the stream is slack the same time as Dover.

At the Kentish Knock L.V., the stream is slack nine minutes after Dover.

Lastly, off the North Foreland, the stream is slack the same time as Dover.

Between these stations and the meridian of 3° 0′ E. we find the following intervals.

In the parallel of Cromer, twenty-four minutes before Dover; at the next station, southward, twenty-four minutes after; at the next, four minutes after; then, thirty-six minutes after; at the next, nineteen minutes after; at the next, three minutes after; and lastly, off the North Foreland, the same time as Dover.

In the first set of comparisons the differences are not greater than might be attributed to the ordinary irregularity of the tides; in the second we discover a progressive increase, and then the phase of the stream seems to be inverted, until at the end of the series we find the interval vanish, and the stream to turn with the high water on the shore.

Retardation of the turn of the stream towards the coast of Holland.

To the eastward of 3° of longitude, the times of slack water get considerably later in that part of the Channel which lies between the northern limit of the Thames and the Texel, and the phase of the stream in all this portion of the North Sea appears to be inverted; the intervals also to get *longer* as the Dutch coast is approached. The occurrence of this *inversion of the phase of the stream with the inversion of the phase of the establishments on the coast of Holland, and its position occupying the site of the node of the tide in Professor* WHEWELL'S *chart of cotidal lines,* is a coincidence which ought not to be overlooked, although I am not able to discover any connection between the phenomenon, which is evidently the cause of the unusual retardation of the stream above-mentioned, and the phenomena of the cotidal chart.

Cause of the retardation of the turn of the stream towards the coast of Holland.

There seems to be very little doubt that the retardation of the stream, and the consequent inversion of phase now noticed in all this part of the Channel, is entirely owing to *the outer stream setting round the Texel,* at a time when the stream is slack in all other parts of the Channel and preparing to go round*.

An inspection of the Plan for one hour after high water will clearly show this to be the case; it will there be seen that the stream of the Channel is making an effort to run to the northward, and on the western side of the Channel has succeeded, the North Sea (or outer) stream being in that part favourable to it; but on the *eastern* side of the Channel, the stream coming round the Texel forces its way up the Channel, and creates a temporary disturbance, which is no doubt the cause of the retardation of the turn of the stream in this vicinity.

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* See Chart one hour after high water, Plate XXXIII.

The two consecutive charts strengthen this supposition, by exhibiting the Texel stream receding as the Channel stream gains strength.

Comparison of time of slack water in the North Sea with the time of high water at Dover.

If, then, we except such observations as are shown to be due to the disturbance from the Texel tide, we shall find that *in the whole extent of channel from Cromer to the North Foreland, there is not half an hour of retardation in the time of slack water from the time of high water at Dover, while in the establishments there is an increase of at least five hours.* That we may appreciate this very small difference of the time of slack water throughout the Channel and the time of high water at Dover, let us inquire what takes place in parts of the North Sea, which exhibit the ordinary phenomena of tides under the influence of a progressive wave, such for instance, as are comprised in the space between Kinnaird's Head and the estuary of Lynn. There is in this space an increase of tidal establishment of five hours, an amount about equal to that which exists between Lynn and Dover. By the Admiralty Tide Tables, it will be seen that in this space there are nearly five hours' retardation in the time of slack water in the offing, making at least, *hour for hour in the change of the stream with the change of establishment*; whilst in the North Sea, in the same change of establishment, there is scarcely *half an hour difference of time in the change of stream.*

Comparison of time of slack water in the English Channel with high water at Dover.

If now we take the English Channel, we shall find half-way between the Start and Alderney, that the stream *turns with the high water at Dover.* Off Portland, *nine minutes before*; off St. Albans, *three minutes before*; between the Isle of Wight and Cape Barfleur, *fifteen minutes after*; and so we run on, the differences varying from *eight minutes one way to an extreme of forty-two minutes the other**. In the Baie de la Seine, the turn of the stream is earlier in the western part than towards its eastern extremity, but the formation of the coast about Cape Barfleur will fully account for this.

In the eastern part of the Baie de la Seine a retardation occurs towards the Somme; in that direction the turn of the stream, on the south side of the Channel, *is an hour later than* on the north side opposite; the observations, however, upon that coast are not given in a manner sufficiently clear, and they were made many years ago, and compared with the establishments of ports, which might not at that time have been very accurately determined; therefore I would not dwell much upon them*.

Upon the whole, therefore, judging from the observations which have been collected, there seems to be sufficient evidence to warrant the conclusion, that, with the exceptions arising from extraneous causes, which are now known, and for which an allowance can be made, the streams of the Channel turn sufficiently near to the times of high water on the shore of Dover to be considered as simultaneous, without occasioning any error that can be of the smallest consequence to shipping*.

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* The vessel now about to sail to continue this inquiry, will, it is hoped, get some observations in this quarter.—November 5. Recent observations have shown these intervals to be in excess.

On the rotatory motion of the stream.

I shall now pass to the next point of interest,—the supposed rotatory motion of the stream in the English Channel and the North Sea. It will be seen by the Charts, that wherever any circular motion of the water appears, it occurs between the outer extremities of the Channel tide and the stream of the oceanic or parent wave; and is clearly to be accounted for by the streams acting obliquely upon each other.

Erroneous ideas respecting this motion.

Captain **Martin White** and Mr. **Græme Spence**, who have written upon the tides of the English Channel, were of opinion that this rotatory motion was not only applicable to the whole of the Channel, but common to the tides of all the world. Captain **White**, in his remarks upon currents, &c., observes, at p. 35, "Tides are governed by a regular periodical reciprocation in most parts of the world, making the round of the compass almost everywhere during the twelve hours. This rotatory motion," he continues, "is perfectly symmetrical during and after a series of moderate weather, and the curves it assumes resemble the form of *spiral curves*." It was Mr. **Græme Spence**, however, who originated this idea of a revolving tide†. It is a singular circumstance that the observations of these officers should not have extended to parts of the Channel where the stream runs true, but have been confined to the mixed tide. Mr. **Græme Spence** obtained his observations in the vicinity of the Scilly Islands, where the streams of the Atlantic and of the English Channel unite; Captain **White**'s observations extended further up the Channel, but still not far enough to be clear of the effect of the Gulf of St. Malo. M. **Monnier**‡, who has often been quoted as the well-known author of a pamphlet on the tides of the English Channel, derived opinions similar to those above-mentioned, from observations made about the Channel Islands also; and was confirmed in his opinions by some observations made about the same time by Captain **Hewitt** in the North Sea, near the Lemon and Ower sands, which, curiously enough, are on the border of the mixed tide of the

Cause of this erroneous opinion accounted for.

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* In my paper upon the tidal phenomena of the Irish Sea, I particularly referred to the nearly simultaneous turn of the stream in that channel which is also under the influence of a combined wave. Since that time observations have been made at the Smalls Lighthouse, at the Kunibeg and at other light-ships; all of which have confirmed in a very satisfactory manner those remarks.

At the Smalls, for instance, situated at the entrance of the Irish Channel, and differing from Liverpool nearly five hours in its establishment, the time of slack water occurs *fourteen minutes* only before high water at Liverpool; at the Kunibeg, *twenty-one minutes before*; then the mean of the intervals in the first page of observations, between Smalls and Bardsey, gives *four minutes after Liverpool*; the mean of the next page of observations thence to Holyhead, *thirteen minutes after*; going northward, the mean of the next page, *twelve minutes after*; off the Isle of Man, *at the same time*; and in the North Channel, *twenty-four minutes after*.

So that throughout the Irish Sea, as in the Channel which separates England from the Continent, the stream slacks throughout at nearly the same time as the combined wave is matured; or as the time of high water at *the virtual head of the tide*, as already stated in my first report.

† See his observations on the tides of the Scilly Islands.

‡ Mémoire sur les Courants de la Manche.

On the rota-ory motion ofthe stream.

North Sea, as those of Mons. Monnier were on the border of the mixed tide of the other sea. These authors have been followed by other talented men, until a common opinion was gaining ground that streams in general had a rotatory motion.

Had the observers above-mentioned made their observations anywhere between the Start and Beachy Head, or between Cromer and the North Foreland, a different result would have been obtained; for in all this space, occupying nearly 360 miles in extent, the stream runs steadily throughout both tides, scarcely changing its direction for four hours and upwards, and then only preparatory to going round to the new coming tide.

xplanation f Plan 1, Plate XL.

Upon Plan 1, Plate XL. I have given examples of the streams in question. The upper figures represent the revolving tides, exactly in the order in which the observations were made, on a direct line between the Texel and Cromer. The circular arrows show the direction in which the stream revolves, and the figures against the arrows the times before and after high water in which the streams run in those directions. The second line of revolving tides was observed in the mixed tides off the Start, and is similar to those off the Texel. The lower lines are samples of the steadiness of the stream which prevails throughout the ordinary tides of the Channel; the stations are given exactly as they occurred on a parallel of 52° 15′ N., which nearly intersects the position Professor Whewell has assigned to the node of the North Sea tide, and as they were observed in the English Channel between Portland and Beachy Head.

It was in the upper or revolving streams that the late Captain Hewitt's observations were made, and in the second row, or similar tides, that M. Monnier and Captain White made their observations; and there can no longer be any doubt that the rotatory tides are the exceptions to the general courses of the stream, and not the rule.

On the time when the stream ttains its maximum rate.

The time at which the stream attains its maximum rate in the Channel is another point of interest and of importance to the seaman. In the 'Pilote Française' we find numerous observations carefully drawn out, and all giving nearly the same result, which is to place the strongest part of the stream at high and low water, and the slack water at half-tide. In 'Mémoire sur les Courants de la Manche,' before referred to, we read at p. 15, "On conclura de ce qui vient d'être dit que l'heure de la haute mer doit coincider avec celle ou le courant de flot acquiert sa plus grand vitesse...... On concevra de la même manière que le courant de jusant doit atteindre sa plus grand vitesse au moment de la basse mer.....:" and in a work of high authority published in this country, it is stated, doubtless from the authorities beforementioned, that "in mid channel the motion of the water will be flowing most rapidly up the Channel at the time of high water, and its motion upwards will cease when the water has dropped to its mean height."

This idea of M. Monnier, viz. of the strongest part of the stream occurring at high water on the shore, is part of the same error which the author before quoted had fallen into respecting the turn of the stream in the Channel, viz. that of comparing the observations with a false standard. Taking the same observations and comparing them with the high water at Dover, the times in question all give the half-tide as the period at which the stream attains its greatest strength; and by referring to another table, in which our own observations are compared, a precisely similar result is obtained. The question is a very simple one, and rests entirely upon the truth of the observations, a specimen of which I have given in the subjoined Table for the purpose of consultation.

The time at which the stream attains its maximum rate.

Table showing the time at which the stream attains its greatest strength, and also its rate per hour at that time.

English Channel.						North Sea.					
No. of station.	Time from high water, Dover.	Rate of stream.	No. of station.	Time from high water, Dover.	Rate of stream.	No. of station.	Time from high water, Dover.	Rate of stream.	No. of station.	Time from high water, Dover.	Rate of stream.
	h m	Knots.		h m	Knots.		h m	Knots.		h m	Knots.
12	3 15	1 81	G	2 50	5 00	3	4 40	1 18	41	2 30	2 35
	2 30				4 50	4	3 00	2 07		2 10	2 35
13	3 00	2 27	H H	2 34	2 30		2 45		42	3 00	2 30
	3 30			2 00	2 30	6	2 30	2 53		2 30	2 45
14	2 15	2 05	E E		2 00		2 15		43	3 00	2 70
	2 00				2 00	8	3 00 E.	2 84		2 30	2 90
15	3 15 E.	3 80	D	3 00	3 70	10	3 00	2 25	44	3 15	2 40
16	3 15	3 14		2 40	3 70		3 00				
	3 00		O	2 45	4 50	12	3 30	1 65	45	3 00	2 60
17	2 30	3 30		3 50	3 60		3 30			3 00	2 21
	3 00	2 75	48	3 00	3 2	13	3 30	1 60	46	3 00	1 85
18	2 15	2 20		3 40	3 0		4 00			2 00	2 00
	3 00	1 60	79	3 00	3 15	14	3 00	1 37	100	2 35	2 60
19	2 45	2 75		3 00	2 90		2 45			3 00	2 60
	3 00	2 00	47	3 00	3 4	15	3 30	1 54	101	2 45	2 00
20	2 30	2 25		2 15	3 2		3 45				
	3 30	1 80	46	2 10	3 6	17	2 45 E.	2 91	102	3 00	1 60
A A	3 20 E.	1 30		3 30	3 3	18	3 30	2 44		1 45	1 85
A	3 20	1 20	49	2 10	3 3		3 30		102A.	3 00	
B	2 10	2 00		3 30	3 1	19	2 45 E.	2 33		2 30	
	3 20	2 50	58	In the Baie de la Seine.	3 2	39	2 30	2 25	103	2 45	1 70
C	2 20	3 80				45	4 00	2 10		1 35	2 15
	3 00	3 80	77	2 30	3 6		2 30		104	3 00	2 60
D	2 45	3 86		3 00	3 15	37	4 00	3 00		3 15	3 00
	3 15	4 33	61	2 5	3 2		2 45	2 40	107	3 30	1 40
E	2 40	2 80		3 5	3 0	38	2 40	2 50		3 20	3 00
	3 10	2 80	75	3 00	3 5		2 45	2 18			
E*a*	2 30	2 80		2 30	2 9	39	2 30	2 50			
	3 30	2 80	76	2 50	3 6		2 45	2 35			
				3 00	3 20	40	3 00	2 40			
							2 45	1 64			

In the 2nd, 5th, 8th and 11th columns of this Table are given the times before and after high water at Dover at which the stream attains its greatest strength, which is clearly seen to be about the time of *half-tide*, Dover, and not, as supposed, at high and low water on the shore.

Direction in which the stream turns.

The *direction in which the stream turns* will next engage our attention. This is a question more curious than useful to the navigator; it is nevertheless one of interest, and I have given it my attention.

Upon Plate XXXII., I have shown, by curved arrows, the direction in which the streams in all parts of the Channel pass through their various rhombs, and I cannot discover that there is any general rule with respect to *particular sides of the Channel.* On the contrary, the direction appears to be wholly dependent either upon the course of that stream which commences first or continues the longest, or upon that which becomes the most powerful, and which, acting obliquely upon the weaker stream, compels it to partake of its own direction. A good example of this may be seen in the chart of the streams at three hours after high water (Plate XXXV.), where the incoming Ocean stream off the Lemon and Ower is dividing the Channel stream and causing all the tides to the eastward of that spot to turn *with the sun,* and those to the westward of it in a *contrary direction.*

On a supposed tide and half-tide.

I have now only to mention a popular error which still exists with reference to the streams of our channels, viz. a belief in a "*tide and half-tide*;" by which it is understood that the stream runs half a tide longer near the centre of the Channel than it does near the coast. So general an opinion requires substantial proof to invalidate it, and I must refer once more to the diagrams which accompany this report. It will be seen there that in no part of either channel does the change of stream in the centre differ even an hour from the change of stream as near the land as a vessel would be safe in navigating, except in that part of the North Sea which is affected by the tide sweeping round the Texel; and then, at the most, it amounts only to a quarter-tide. It is not difficult to discover that this error has arisen from the confusion of high water on the shore with the time of slack water in the offing.

I have now described the principal features of the tidal streams of this strait, and it is evident from the observations which have been collected that the laws by which the streams of these channels are governed, differ materially from those which regulate the streams of ordinary tides.

It will be interesting to see in what this consists, and to endeavour to account for the cause.

Peculiarity of the wave of the English Channel and North Sea.

Under ordinary circumstances, such as those which attend the passage of a *single tide*-wave up an estuary or deep gulf, or even along an open coast, we find *a progressive turn of the stream to accompany a progressive increase of establishment.* But in the channels under discussion the stream is found to turn *nearly simultaneously throughout the strait,* wholly regardless of the *order of its establishments,* and to reverse *with the time at which a wave peculiar to such channels is matured.*

This wave, which exercises so singular an influence over the streams of these Channels, is occasioned by one portion of the oceanic tide-wave of the Atlantic passing round the north end of the British Islands, while the other finds its way up the English Channel and meets it in the Strait of Dover. In consequence of this meeting or opposition, the character of the wave is changed; its dimensions become diminished just one half in extent, its rate of travelling is reduced a like quantity, and its streams are almost always in opposition to those of the outer or parent wave.

Formation of a combined wave in the Strait of Dover.

Plans 3 and 4 exhibit the forms of this wave at full and change, as they appear at the hours respectively marked against them at the side of the Plan. They are constructed principally from the establishments and ranges of tide published in the Philosophical Transactions, 1836, Part II., by drawing a line through the fairway of the Channel, and setting off upon it the times of high water and the ranges of tide as they would exist at the stations selected for this purpose.

In these Plans we can distinctly trace the formation of a combined wave at Dover. In Plan 4, for instance, at V hours, the crests of two waves are seen to be formed a little beyond the Deadman on one side and at the Spurn Point on the other, and the foot of the wave or hollow which they create is resting at Dover. Following the progress of these two crests down the page, we find them gradually approaching each other and wearing out the depression in advance of them, until between VIII. and IX. o'clock the hollow has vanished; at X. o'clock there is a decided convexity of surface, which gradually increases until at XI. o'clock, Plan 3, the crest has attained its zenith: the combined wave is perfected, and it is high water at Dover.

If now we follow the wave down the same page, Plan 3, as the tide falls, we find the crest to become more oblate, and finally, to be obliterated without there being any material progress of the wave in either direction. In fact, the wave on this section appears to descend nearly perpendicularly, and the progress of the derivative waves to be so far destroyed that we can scarcely trace any indication of their advance. On the contrary, we see a new wave on each side preparing to roll up the Channel to renew the wave thus clearly common to both. So far then we perceive, from these data, that the wave in the Strait of Dover is due to the combined action of two waves derived from the parent or Atlantic wave, and which advance from opposite quarters. These waves, it may be seen, are materially different in their dimensions and rate of travelling from those of the oceanic wave from which they are derived. The dotted line drawn through the crests of the wave upon the Plan 3, will sufficiently discover the material change it undergoes on approaching the channel in which the branch wave exists.

The same result, nearly, as regards the formation of the combined wave, is arrived at if we take a mean between the sections of the wave as it would appear from the ranges and establishments along the coasts of England and of France and Belgium. In this mean section, however, we trace the formation of a combined wave at IX. o'clock off Selseabill, and can detect a progressive advance of a small wave thence to the eastward, making high water along the Dutch coast in the inverse order of the high water resulting from the wave upon the opposite side of the channel, and then merging into the wave preparing to renew the order of the tides in the North Sea*.

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* This merging of the waves into each other may possibly be the cause of the whole rise of the tide at the Texel occurring in the first half of tide, as stated in "Ariel," Remarks upon the Tides of the Texel, published at Amsterdam.

This wave is not, however, of sufficient magnitude to affect *the streams* which traverse its surface, which seem to be under the entire control of the combined wave. The inverse order of the establishments upon the coast of Belgium and of Holland is a point of considerable interest, and I greatly regret that the season has been so unfavourable that no observations have been made which throw any additional light upon the subject.

If we place the mean water-level of the middle sections of the wave together, we shall form the figures traced in Plan 2, Plate XLI., and shall be struck with the very small limits off Harwich through which the large wave at Dover is transmitted; this contracted portion of the sketch is nearly in the situation in which Professor WHEWELL has drawn the node of the North Sea tides.

Powerful influence of the combined wave over the streams of the Channel.

The influence of the combined wave over the tidal phenomena of the channels on both sides of the Strait of Dover is very remarkable. The streams of both it will be seen reverse together as the wave is matured; they extend to the same distance from the apex of the wave, where they are met by rotatory streams; in short, the whole tidal feature of one-half of the strait bears so close a resemblance to that of the other as to leave no doubt of their being both due to a common impulse. For instance, it may be seen in the Plans which accompany this report, that in the North Sea the streams of the oceanic and Channel wave meet off the estuary of Lynn, as they do off the estuary of St. Malo in the English Channel, at the same hours and at the same distances nearly from the head of the combined wave; that there is an increased rise of the tide at Lynn as in the Gulf of St. Malo, although not to the same extent, owing perhaps to a different conformation of coast, but sufficiently large to establish the similitude, being in both cases nearly double that of the offing rise; that in these localities, on both sides, the streams are all of a rotatory character, and that from the meeting of the streams off Lynn to the meeting of the streams off Dover, there is, as in the English Channel, from the meeting of the streams off St. Malo, to the meeting of the aforesaid streams off Dover, a stream which flows steadily on both sides towards Dover, whilst the water is *rising* at that place and sets *away from it*, whilst the water is *falling* there; each portion having the remarkable peculiarity of reversing its stream throughout nearly simultaneously with the time at which the combined wave is matured.

Streams of the Irish Channel under a similar influence.

I may here observe, that in this respect the Irish Channel is precisely under the same circumstances as the English Channel and North Sea. The tide-wave enters that sea in like manner by opposite routes, and forms one vast wave, having all the peculiarities of a combined wave. On each side of the apex of this wave the streams reverse throughout at nearly the same time; that time corresponding with the time at which the combined wave is perfected, as occurs with the streams in the English Channel.

In the Irish Channel the streams are even more regular than those of the North Sea and English Channel, and suffer less disturbance from the ocean or offing streams. It is true that in the Irish Sea there is no intermediate stream where the tides meet, but, on the contrary, a large tract of still water which the streams scarcely ever disturb, but this arises from the different conformation of the inner part of the strait. The Irish Sea, for instance, may be said to be contracted at its entrances, and to expand into a large inland sea in its centre, whereas the other channel has wide entrances and a very contracted centre. They are, however, both canals in which the waves from two tidal seas enter at opposite ends and meet in the centre, where they form a combined wave, and hence they have the property of reversing their streams simultaneously.

Tidal phenomena of the Irish Sea and of the English Channel compared.

There cannot therefore be any doubt that the waves which are formed in the centre of these straits exert a powerful influence over the course of the waters on both sides of them, and in fact that they both govern their movements and regulate the limits of their streams.

It was the consideration of this influence that determined me to refer all the movements of the streams of these Channels to the time when the combined wave was matured. In the Irish Sea I adopted Liverpool as the standard*, and as Dover was situated so near to the apex of the wave in the English Channel, and had tables of its tides already printed and in general circulation, I adopted the time of high water at that place as a standard to which all the observations there should be referred.

I shall now compare the general inclination or slope of the surfaces of the combined wave on both sides with the direction of the streams passing along the Channel at the moment, for the purpose of showing the mechanical action of the water, and of tracing the intimate connection that exists between these slopes and the simultaneous turn of the stream.

Comparison of the inclination of the surface of the wave with the direction of the stream along it.

If we direct our view to the inclination of the surfaces of these waves, Plans 3 and 4, Plates XLII. XLIII., we shall see that the directions in which the streams run do not always correspond with the *existing* slopes of the surfaces, as they might be supposed to do from the known law of gravitation, but that during the last half of the tide they are to be traced to the effect of *a previous* and contrary depression. The maximum rate of the stream may be seen to occur when the surface has its smallest depression†, and that there is no stream at all at the moment of the greatest elevation and depression. It will be seen that the rate of the stream depends upon the amount and continuance of the inclination; and also that a stream, when once produced, will continue its progress for a length of time, although the inclination that produced it may have been reversed by the passage or descent of the crest of the wave. Consequently from the time of the passage of the wave, or the reversal of the inclination of its surface, until the stream finally ceases to flow, the water will be seen to run up an inclined plane, and will continue to do so for nearly as

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[*] See my paper in Philosophical Transactions, Part I. 1848.

[†] The maximum rate of the stream is shown in the Table at page 711 to occur at half-tide, at which time the wave is seen to have the smallest depression.

long an interval before it be brought to rest as it did to acquire its momentum, the relative inclinations at the beginning and end being about the same.

The reversal of the stream throughout the strait at the same time will not therefore be a matter of surprise, as it will be seen to be only the effect of gravitation due to *the general slope* of the surface. That it is the *general slope* of the surface of the combined wave that occasions the stream throughout these channels, is even more manifest in the North Sea than in the English Channel, from the fact of the stream there pursuing a steady course between two shores, of which the order of their tidal establishments is inverted without reference to either.

Cause of the stream explained.

If it be required to trace the streams of the Channel through their gradations, it may be done on Plan 3, thus: at XI. o'clock, it is high water at Dover, the wave has consequently attained its zenith, and the depressions of the surfaces on either side are at their maximum. There is now no stream, because the momentum acquired during a former depression has only now ceased, notwithstanding the increasing obstruction for two hours which has been presented by the reversed inclination of the wave. The water at Dover now falls, the stream begins, and as the depression of the surface continues, the stream gradually acquires strength until about half-tide, when the depression is at its minimum and the strength of the stream at its maximum: after this the inclination of the surface is unfavourable to a continuation of the stream. From this time, therefore, the rate of the stream begins to diminish, because the reversed inclination is progressively becoming more adverse to its progress, and at low water at Dover, after having run up an elevation for two hours, its effort is exhausted and there is slack water throughout the wave, as at first*.

Conclusion.

In conclusion, I trust it will appear to their Lordships, that the means which they have been pleased to place at my disposal have been advantageously employed; and I venture to express a hope, that whilst science will be benefited by the inquiry, the navigation of our channels will be so far improved that the seaman will in future find his course through these moving waters rendered simple and plain. Hitherto the numerous and perplexing references which he has been compelled to make to establishments of ports, with some of which he was not even furnished, and which, under any circumstances, rendered a calculation necessary, have in too many instances, it is feared, caused the set of the tides to be wholly disregarded, or what is worse, misapplied, the consequences of which, it is now seen, are very likely to have been attended with disastrous results. For instance, the meeting of the streams off the Casquets and the Start in the English Channel, and the direction there given to the water at a particular time of the tide, will fully account for the numerous wrecks about the Channel Islands; whilst near the Strait of Dover an unexpected set of the stream directly down upon the Somme, and in a part of the Channel where from its narrowness a true stream might be expected, is evi-

Beneficial results of this inquiry to the seaman.

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* In my report upon the streams of the Irish Sea, Philosophical Transactions, Part I. 1848, at figures A and B the effect is there shown to be precisely the same.

dence of the danger of approaching this part of the Channel if ignorant of the set of the stream; and most singularly this unsuspected evil occurs exactly in the spot where those disastrous wrecks of the Conqueror and Reliance took place, and where the Curaçoa, one of Her Majesty's frigates, so narrowly escaped a similar fate.

Henceforward a simple reference to a Dover tide table will enable the mariner to determine in which direction his vessel is being carried, assured that whilst the water is rising at Dover he will have a fair stream from the Lemon and Ower to the North Foreland in one channel, and from Alderney to Beachy Head in the other, and *vice versâ*; whilst the times and places of the meeting of the streams will be apparent upon the Plan, so that it is hoped, when the contents of the present paper are sufficiently known and circulated, they will be the means of diminishing the number of those losses of both life and property with which the annals of LLOYD'S abound, and of advancing our knowledge of the tides by the practical illustration of the phenomena of the tidal streams of straits under the influence of a combined wave.

In closing this report, I particularly wish to observe that my thanks are due to the officers whose names have been mentioned as having contributed to this inquiry, and especially to the Trinity House and Captain BAX, to whose exertions in training the light-vessel keepers the observations made by them owe their value; and to Captains WASHINGTON and BULLOCK and the officers, who have been engaged in both making the observations and drawing the plans.

To you, Sir, I am indebted for the unremitted assistance you have rendered this cause by the exercise of a zeal which is ever forward in promoting whatever tends to the improvement of navigation or to the advancement of science.

I am, Sir, your humble Servant,
F. W. BEECHEY, Captain R.N.

To Rear-Admiral Sir Francis Beaufort, K.C.B.,
&c. &c. &c.,
Admiralty.

Note.—Since this report was forwarded, observations have been made between the Spurn and Helgoland, and it appears that in all that part of the sea lying between the rotatory streams off the Texel and Helgoland, or rather between 2°·30 E. and 7°·30 E., the stream *turns nearly simultaneously* with the time of high water at Helgoland and at Dover, the establishments of those places being nearly the same. We may therefore look for a combined wave at the mouth of the Elbe, and for a succession of rotatory streams extending to a considerable distance in a north-easterly direction from Lynn. A few observations have been made in the English Channel also which confirm our former results, and show that such of the observations of the French surveyors referred to in p. 708 as have been tested, were in excess, as had been anticipated.—F. W. B.

Explanation of the Plates.

Chart of the places of observation	Plate XXXII.
Chart of the stream at one hour after H.W.	Plate XXXIII.
Chart of the stream at two hours after H.W.	Plate XXXIV.
Chart of the stream at three hours after H.W.	Plate XXXV.
Chart of the stream at six hours after H.W.	Plate XXXVI.
Chart of the stream at five hours before H.W.	Plate XXXVII.
Chart of the stream at three hours before H.W.	Plate XXXVIII.
Chart of the stream at one hour before H.W.	Plate XXXIX.
Plan 1. Rotatory and true streams compared	Plate XL.
Plan 2. Mean section of Channel wave	Plate XLI.
Plan 3. Hourly section of the rising tide-wave	Plate XLII.
Plan 4. Hourly section of the falling tide-wave	Plate XLIII.

CHART
Shewing the situation of
the Places at which
TIDAL OBSERVATIONS
have been made; and also the direction
in which the streams (ebb & flood) turn.

To accompany Capt. Beechey's paper on the Tides.

References.
◎ *Revolving Streams.*
◠ *Inward stream turns.*
◡ *Outward stream turns.*

CHART
Shewing the situation of
the Places at which
TIDAL OBSERVATIONS
have been made: and also the direction
in which the streams run at 1 Hour
after High Water at Dover.
Lat.
15
30
45
60
49°
50
51
52
53
54
Scale of Miles.
Long.
One degree.
To accompany Capt. Beechey's paper on the Tides.
References.
Revolving Streams.
Inward stream turns.
Outward stream turns.
BRISTOL CHANNEL
ENGLAND
NORTH SEA
FRANCE
HOLLAND
Stream influenced by the rivers
ZUYDER ZEE
Smalls
Caermarthen
Helwick
Port Talbot
Lundy I.
Cardiff
R. Severn
Bridgewater
Scilly I.
Penzance
Falmouth
Plymouth
Eddystone
Dartmouth
Exeter
Lyme Regis
Weymouth
Portland Bill
Southampton
Portsmouth
Chichester
I. Wight
Shoreham
Brighton
Newhaven
Beachy Hd.
Rye
Dungeness
Dover
North Foreland
Sheerness
Greenwich
R. Thames
Maldon
Harwich
Orfordness
Lowestoft
Yarmouth
Cromer
Cley
Hasbro
Leman & Ower
Newarp
Dudgeon
Lynn
Boston
Wainfleet
Saltfleet
Spurn Hd.
Hunstanton
Kentish Knock
Galloper
Ushant I.
Brest
Alderney
Guernsey
Jersey
Sark
Cherbourg
C. Barfleur
Granville
S. Malo
Avranches
Pontorson
Havre
Honfleur
R. Seine
Caudebec
Rouen
Dieppe
St. Valery en Caux
R. Somme
Abbeville
Etaples
Boulogne
Calais
Gravelines
Dunkirk
Ostend
The Hague
Amsterdam
Texel
Helder
Harlingen
Emden
The Dollart
Heligoland
Cuxhaven
Belle I.
L'Orient
Port Louis
3
2
1° W
0
1° E
4
5
6
7
8
9
10

CHART
Shewing the situation of the Places at which
TIDAL OBSERVATIONS
have been made; and also the direction in which the streams run at 2 Hours after High Water at Dover.

To accompany Capt. Beechey's paper on the Tides.

References.
Revolving Streams.
Inward stream turns.
Outward stream turns.

CHART
Showing the situation of
the Places at which
TIDAL OBSERVATIONS
have been made; and also the direction
in which the streams run at 3 Hours
after High Water at Dover.

To accompany Capt. Beechey's paper on the Tides.

References.
◎ Revolving Streams.
◠ Inward stream turns.
◡ Outward stream turns.

CHART
Shewing the situation of the Places at which
TIDAL OBSERVATIONS
have been made; and also the direction in which the streams run at 6 Hours after High Water at Dover
Lat.
15
30
45
60
49°
50
51
52
53
54
Scale of Miles.
Long.
One degree
To accompany Capt. Beechey's paper on the Tides.
References.
Revolving Streams.
Inward stream turns.
Outward stream turns.
BRISTOL CHANNEL
ENGLAND
NORTH SEA
HOLLAND
FRANCE
ZUYDER ZEE
Smalls
Caermarthen
Helwick
Port Talbot
Lundy I.
Cardiff
Chepstow
R. Severn
Bridgewater
Scilly I.
Wolf R.
Penzance
Falmouth
Fowey
Plymouth
Eddystone
Exeter
Lyme Regis
Weymouth
Portland Bill
Southampton
Portsmouth
Chichester
I. of Wight
Brighton
Newhaven
Beachy Hd.
Rye
Dungeness
Dover
North Foreland
Sheerness
R. Thames
Greenwich
Maldon
Harwich
Orfordness
Lowestoft
Yarmouth
Newarp
Haisbro
Leman & Ower
Cromer
Dudgeon
Lynn
Boston
Spurn Hd.
R. Humber
Saltfleet
Galloper
Goodwin Sands
Ushant I.
Brest
Isle Bas
Sept Isles
Brehat
Guernsey
Alderney
Casquets
Jersey
Cherbourg
C. Barfleur
Carteret
Minquiers
S. Brieux
S. Malo
Granville
Avranches
Pontorson
Caen
Havre
Honfleur
R. Seine
Caudebec
Rouen
Dieppe
Abbeville
Etaples
Boulogne
Calais
Gravelines
Dunkirk
Ostend
The Hague
Amsterdam
Texel I.
Emden
The Dollart
Heligoland
R. Weser
Quimper
L'Orient
Port Louis
Belle I.
7
6
5
4
3
2
1° W
0
1° E
2
3
4
5
6
7
8
9
10
48
49
50
51
52
53
54
55

CHART
Shewing the situation of
the Places at which
TIDAL OBSERVATIONS
have been made; and also the direction
in which the streams run at 5 Hours
before High Water at Dover.

To accompany Capt. Beechey's paper on the Tides.

References.
◎ Revolving Streams.
◠ Inward stream turns.
◡ Outward stream turns.

J. Basire sc.

CHART
Shewing the situation of
the Places at which
TIDAL OBSERVATIONS
have been made; and also the direction
in which the streams run at 3 Hours
before High Water at Dover.
15
30
45
60
49°
50
51
52
53
54
Lat.
Scale of Miles.
Long.
One degree
To accompany Capt. Beechey's paper on the Tides.
References.
Revolving Streams.
Inward stream turns.
Outward stream turns.
BRISTOL CHANNEL
ENGLAND
NORTH SEA
HOLLAND
FRANCE
ZUYDER ZEE
Scilly I.
Lundy I.
Carmarthen
Helwick
Port Talbot
Cardiff
R. Severn
Bridgewater
Minehead
Padstow
Falmouth
Plymouth
Eddystone
Start Pt.
Dartmouth
Exeter
Lyme Regis
Weymouth
Portland Bill
Poole
Southampton
Portsmouth
Chichester
I. of Wight
Shoreham
Brighton
Newhaven
Beachy Hd.
Rye
Dungeness
Dover
North Foreland
Sheerness
Greenwich
R. Thames
Maldon
Harwich
Orfordness
Lowestoft
Yarmouth
Caister
Newarp
Haisbro
Leman & Ower
Cromer
Cley
Dudgeon
Lynn
Boston
Wainfleet
Saltfleet
R. Humber
Spurn Hd.
Kent. Knock
Galloper
Ushant I.
Brest
Isle Bas
Sept Isles
Brehat
Quimper
Glenan I.
L'Orient
Port Louis
Belle I.
S. Brieux
C. Frehel
S. Malo
Granville
Avranches
Pontorson
Jersey
Guernsey
Sark
Alderney
Casquets
Cherbourg
C. Barfleur
Carteret
Carentan
Caen
Honfleur
Havre
R. Seine
Caudebec
Rouen
Dieppe
S. Valery en Caux
S. Valery sur Somme
R. Somme
Abbeville
Etaples
Boulogne
Calais
Gravelines
Dunkirk
Ostend
The Hague
Amsterdam
Texel I.
Harlingen
Stavoren
Emden
The Dollart
Norden
Helgoland I.
Cuxhaven
Bremerlehe
R. Weser
R. Elbe
3
2
1° W
0
1° E
4
5
6
7
8
9
10
J. Basire sc.

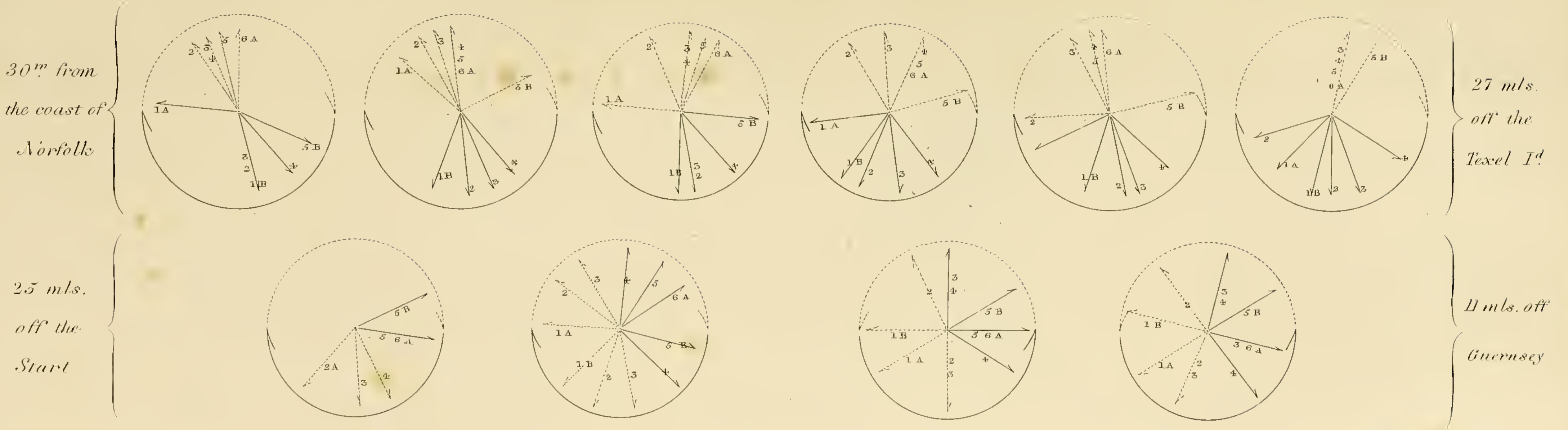
CHART
Shewing the situation of
the Places at which
TIDAL OBSERVATIONS
have been made; and also the direction
in which the streams run at 1 Hour
before High Water at Dover.

To accompany Capt. Beechey's paper on the Tides.

PLAN I.

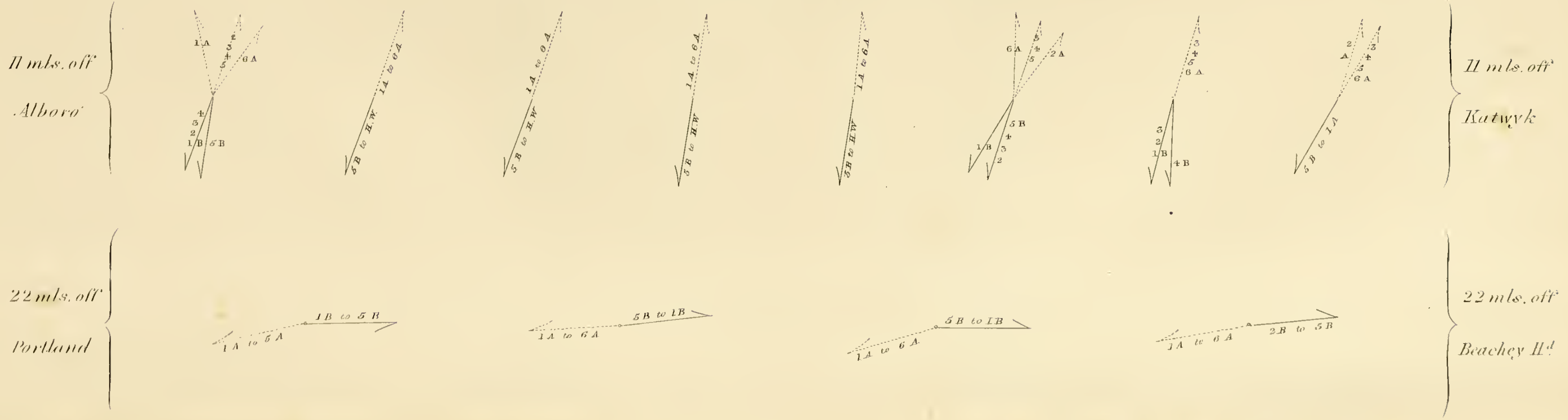
Shewing the course of the stream both in the revolving and in the true Tides of the North Sea and English Channel.

REVOLVING TIDES.



TIDES

observed in the true stream of the Channel.

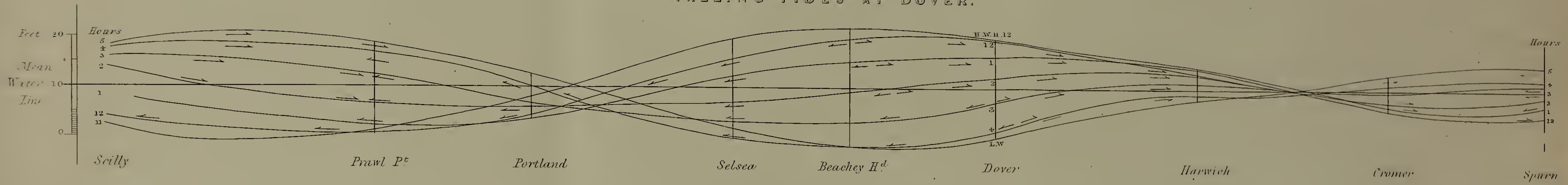


BRITISH MUSEUM NATURAL HISTORY

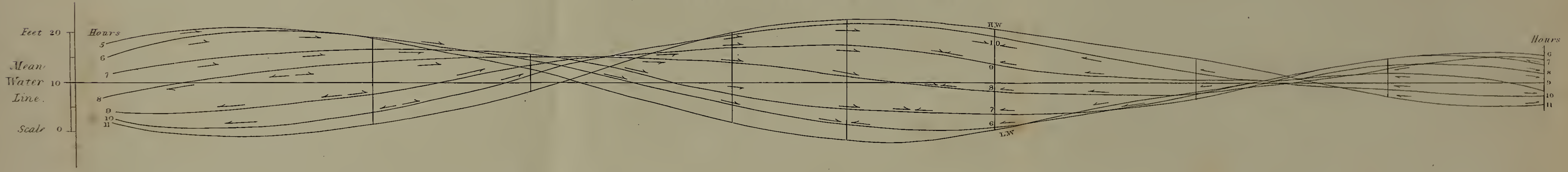
PLAN 2.

Shewing the form of the surface of the water, and the direction of the stream between Scilly and Spurn Pt at each hour of the Tide.

FALLING TIDES AT DOVER.



RISING TIDES AT DOVER.



These sections are THE MEAN *of the Wave Lines as they occur upon the English and French Coasts.*

J. Basire sc.

PLAN 3

Exhibiting the Exaggerated form of the surface of the Tide wave between Cromarty and the Lands End at every hour of the tide. (Dover Establishment.)

Compiled from data in Professor Whewells paper on the Tides Phil. Trans. 1836. and in the Annuaire des Marées des Côtes de France 1848. etc the direction of the stream excepted

To accompany - Capt. Beechey's report upon the Tides of the English Channel

J. Basire, Litho.

PLAN 3

Exhibiting the Exaggerated form of the surface of the Tide-wave between Cromarty and the Lands End at every hour of the tide. (Dover Establishment.)

From data in Professor Whewell's paper on the Tides Phil. Trans. 1836, and in the Annuaire des Marées des Côtes de France 1848. etc.

the direction of the stream excepted

FALLING TIDES (at Dover)

To accompany Capt. Beechey's report upon the Tides of the English Channel.

J. Basire, Lithe.

XXXI. *On the* MEGATHERIUM (*Megatherium Americanum*, BLUMENBACH).

By Professor OWEN, *F.R.S. &c.*

Part I.—*Preliminary Observations on the Exogenous Processes of Vertebræ.*

Received November 8, 1850,—Read January 9, 1851.

BEFORE entering upon the description of the skeleton of the Megatherium, it is requisite to premise some remarks on the vertebræ of the Mammalia in general. Hitherto these parts have been described by means of the terms supplied by Human Anatomy. But the skeleton of Man is one which deviates most from the common archetype: some parts are developed in excess; other parts, which are present as a general rule in the Mammalian series, are either rudimental or absent. The latter is more particularly the case with those processes of the vertebræ which are developed in relation to the attachment and force of the muscles; and which, being connected with particular modes and media of motion, become eminently significative of the habits and affinities of the species. The consideration and comparison of these processes, therefore, most of which have received no names in Human Anatomy, are essential to a right determination of the habits and affinities of the Megatherium; and in order to make intelligible the terms in which the vertebral peculiarities of that great extinct animal will be described, I propose first to illustrate them by giving a comparative survey of the principal modifications of the exogenous processes in the vertebrate series.

The 'exogenous' processes of a vertebra are those which grow out of the previously ossified parts, and are so classified and named in contradistinction from the 'autogenous' parts or elements of a vertebra which are developed from their own proper centres of ossification*.

In the sixth cervical vertebra, for example, of the human fœtus, the part which SOEMMERRING, the most exact and classical author on Anthropotomy, calls "radix prior seu antica processus transversi vertebræ†," is developed from a separate centre and for some time continues to be a distinct bar of bone; whilst the part called "radix postica processus transversi vertebræ‡," grows out of the base of the "radix arcus posterioris§," as SOEMMERRING denominates the autogenous part which I have called 'neurapophysis:' and from this element, or from the arch formed by its coalesence with its fellow, when it constitutes the "arcus posterior vertebræ" of SOEMMERRING, other processes grow out; as, for example, the "processus obliqui seu articulares superiores et inferiores." These different processes offer many modifications of size and shape, and a certain change of position and direction, when traced through the vertebrate series; in the course of which comparison the anatomist meets with other exogenous processes, traceable with equal certainty from species to species and determinable under all their various modifications: whence it becomes necessary for the purpose of brief and clear description to indicate each of such processes by a single definite name, capable of being formed into an adjective to express the properties or appendages of such processes*.

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* On the *Plesiosaurus macrocephalus*, Geological Transactions, vol. v. 2nd series, p. 518, 1838.

† De Corporis Humani Fabricâ, 8vo. 1794, tom. i. pp. 239, 241. ‡ Ib. § Ib. p. 236.

The convenience of such terms will be admitted by the Human Anatomist who considers that the processes in question have, as yet, received no distinct substantive names in Anthropotomy; and who knows, from Osteogeny, how vaguely some of the descriptive terms, as 'transverse process,' for example, are applied to parts obviously very different in their nature and constitution. The 'transverse process' of a dorsal vertebra is a simple exogenous growth from the neurapophysis, commonly affording an articular surface for a rib; the 'transverse process' of a sacral vertebra† is an autogenous part, which continues distinct long after birth; the 'transverse process' of a cervical vertebra is partly exogenous, partly autogenous, consisting in fact of two distinct processes and a rudimental rib, but distinguished in Anthropotomy from other transverse processes only by 'being perforated.'

But if such common phrase of 'transverse process,' with a note of distinction, as that "it is perforated in the cervical vertebræ," be sufficient for the exigencies and applications of Human Anatomy, it becomes quite inadequate and often totally inapplicable to the answerable parts in the lower animals: in the Crocodile, for example, the cervical rib is much more developed and maintains constantly a free articulation by a 'head' with a well-developed inferior *transverse* process ('radix antica,' SOEMM.), and by a 'tubercle' with an equally distinct superior *transverse* process ('radix postica,' SOEMM.). In the Wombat (Plate XLIV. fig. 12), the Hare, the Pig, and most other quadrupeds, the *transverse* process of the lumbar vertebræ consists of an exogenous base and an autogenous apex, this apex being, as THEILE and MULLER‡ have shown, a rudimental rib like the autogenous part of the transverse process in the neck.

In entering upon the descriptions of the extinct species of the Reptilian class§, the most varied, extraordinary and heteroclite, as CUVIER justly remarks, of any of the

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* This I have done for some years past in my Lectures at the Royal College of Surgeons, in the 'Catalogue of the Human and Comparative Osteology in the Museum of the College,' and in some of my published memoirs: as *e.g.* On the *Plesiosaurus macrocephalus*, Geological Transactions, 4to, 1838. On the Anatomy of the Male Aurochs (*Bison europæus*), Proceedings of the Zoological Society, November, 1848, p. 131.

† "Laterales partes, quæ processus transversos coalitos repræsentant," SOEMM. *op. cit.* t. i. p. 271.

‡ Archiv für Anatomie und Physiologie, Jahrg. 1839. Vergleichende Anatomie der Myxinoiden, in 'Berlin Abhandlungen,' 1836, p. 304.

§ Reports of the British Association, 1839.

lost forms of animal life, I found that a very large proportion of their fossil remains consisted of vertebræ or parts of vertebræ, and that a definite idea of these complex bones, with a substantive nomenclature for their parts, was indispensable in order to give a clear and intelligible description of them. In a memoir on the *Plesiosaurus macrocephalus* read before the Geological Society, April 1838, I therefore defined the parts of the typical vertebra, distinguished the autogenous elements from the exogenous parts, and proposed the nomenclature which I have since used and further illustrated in subsequent works. Referring more particularly to my 'Lectures on the Comparative Anatomy of the Vertebrate Animals*,' and my work 'On the Archetype of the Vertebrate Skeleton†,' for the fuller exposition of the views entertained by anatomists on the nature of the vertebra, it is sufficient for the present purpose to remark, that the term 'parapophysis' was proposed for the 'inferior transverse process,' or 'anterior root of the perforated transverse process of the cervical vertebræ'; the term 'diapophysis' for the 'superior transverse process,' or 'posterior root of the perforated transverse process'; and the term 'pleurapophysis' for that element, which, essentially the same in different regions of the spine, is short, styliform, and speedily anchylosed in the neck of Man, is remarkable for its length and freedom of motion in the back, and is as remarkable for its breadth, thickness, and wedged fixedness in the sacrum; which is hatchet-shaped and free in the neck of the Crocodile and Plesiosaurus; and is as broad and flat, in the first dorsal segment of a Whale, as the ordinary mammalian scapula or any of the 'flat bones' in Anthropotomy.

The necessity for a definite technical term for this vertebral element was the greater because the name 'costa' or 'rib' has not only been withheld in Human Anatomy from the element in question, under every modification save that in which it retains its individuality and mobility with a certain length and slenderness; but it has been extended to another and quite distinct element, viz. the 'hæmapophysis,' which from being commonly cartilaginous in the thorax of Man, has obtained the name of 'cartilage of the rib,' or 'pars cartilaginea costæ.' As this part however is most commonly a distinct ossified part in the air-breathing Vertebrata, it has been called in Comparative Anatomy the 'sternal rib,' in contradistinction to the 'vertebral rib' or 'pars ossea costæ' of Anthropotomy. Both, however, are distinct elements of the 'vertebra' in its true or wider anatomical sense; each may exist independently of the other, and the hæmapophysis is often present in other regions besides the sternal or thoracic one.

The subject, however, of the present communication being the 'exogenous parts of the vertebræ,' I shall return to it by remarking, that, in Human Anatomy, other processes have been recognized besides the 'spine,' the 'zygapophysis' (oblique or articular process), the 'diapophysis' (transverse process and 'radix postica' in the neck) and the 'parapophysis' (part of the 'radix antica' in the neck). MONRO, for example, the first exact describer of Human Osteology, when treating of the lumbar vertebræ, observes,—"5. Betwixt the roots of the superior oblique and transverse processes a small rising may be observed, where some of the 'musculi erectores trunci corporis' are fixed[*]." And SOEMMERRING bears testimony to the accuracy of MONRO's observation of this 'small rising' as a constant part, by calling it "processus accessorius processui transverso et articulari superiori interpositus[†]." There are, in fact, two such accessory processes, as SOEMMERRING, indeed, seems to indicate. One of these 'small risings' or 'accessory processes,' although it seems so insignificant, and is so small, as to be commonly passed over without notice in our modern anthropotomical compilations[‡], is not only so constant as to merit unfailing notice in the human subject; but, in extending our comparisons from Man to the lower mammalia, we find it speedily, in the Quadrumanous Order, for example, gaining a development which makes it, in the dorsal and lumbar regions, more conspicuous than the articular processes themselves: whence CUVIER, observing its relation to the anterior of these processes, calls it "une seconde apophyse articulaire[§];" and M. DE BLAINVILLE, struck rather with the shape of the process, calls it "apophyse styloïde[||];" whilst M. STRAUS-DURCKHEIM, regarding it as a sort of accessory transverse process, prefers to call it "apophyse plagienne[¶]:" I have termed it the '*anapophysis*[**].' The second tubercle is usually a somewhat larger process, situated between the diapophysis and the upper or anterior zygapophysis; it is equally constant in certain vertebræ in Man, and attains in some mammals, the Armadillos for instance, as great a length as the spinous process itself. The part in Man to which I allude is that which the accurate BOURGERY has depicted in his beautiful plates, and indicated as the 'face rugueuse de l'apophyse articulaire supérieure[††].' STRAUS-DURCKHEIM mistakes it for the superior articular process itself, in the feline quadrupeds, calls it 'apophyse antoblique,' and denies the existence of anterior oblique processes in the third to the ninth dorsal vertebra inclusive; which do, in fact, possess the articulating surfaces so called, but want the accessory process which becomes so markedly developed in the posterior dorsal and lumbar vertebræ. For this accessory process I have proposed the name of '*metapophysis*[‡‡],' and have noticed some of its modifications in my 'Anatomy of the Male Aurochs,' in which, as in most other Ruminants, the anapophysis is not present*. The process which is developed, sometimes singly, sometimes in pairs, from the under part of the centrum in some mammals and in most birds and reptiles, I have called '*hypapophysis*†.'

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* 8vo. LONGMANS, 1846.

† 8vo. VAN VOORST, 1848.

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[*] The Anatomy of the Humane Bones, 12mo, 1726, p. 202. In later editions he calls it a 'small protuberance.'

[†] *Op. cit.* tom. i. p. 268. He speaks of two such processes, but whether he meant the pair of metapophyses, or both met- and an-apophysis, is uncertain.

[‡] I may instance BELL's Anatomy, vol. i. 'On the Bones,' &c., ed. 1826, p. 20, and the Anatomist's Vade Mecum, by ERASMUS WILSON, 12mo, 1842.

[§] Leçons d'Anat. Comp., ed. 1835, t. i. p. 197.

[||] Ostéographie, *passim*.

[¶] From πλάγιος, *transversus*. Anatomie du Chat, t. i. p. 95.

[**] From *ἀνὰ retro, ἀπόφυσις processus,* because it generally projects more or less backwards.

[††] Traité Complet de l'Anatomie de l'Homme, fol. t. i. pl. 9. figs. 2 and 4 *k*. This appears to be indicated, in the 5th edition of QUAIN's 'Anatomy,' as a tubercle projecting from the superior articulating process.

[‡‡] From *μετὰ inter, ἀπόφυσις processus,* because it is usually between the transverse process (diapophysis) and the anterior oblique process (prozygapophysis).

I propose in the first place to trace the homologies and to indicate the chief modifications of the metapophyses and anapophyses in the mammalian class, and thereby to vindicate their title to distinct names, and demonstrate the utility, if not the necessity, of such signs for parts so constant in existence and so variable in character in a great proportion of that class. I may remark, also, that as I shall frequently have to allude to the anterior as distinct from the posterior zygapophyses, I shall call the former 'prozygapophysis,' and use the term 'zygapophysis' simply to signify the posterior pair.

* "With regard to the vertebræ of the trunk of the Aurochs, I may remark, that the only accessory process in addition to the ordinary zygapophyses and diapophyses is the 'metapophysis,' which appears as a stout tubercle above the diapophysis in the middle dorsals, and gradually advances and rises upon the anterior zygapophyses in the posterior dorsal and lumbar vertebræ. This process is developed to an equality of length with the spinous processes in the Armadillos. It is commonly associated with another accessory exogenous process, to which I have given the name 'anapophysis' in the Catalogue of the Osteological Series in the Royal College of Surgeons. This process, which in most of the *Rodentia* rises, at first, in common with the metapophysis, as a tubercle above the diapophysis, separates from the metapophysis as the vertebræ approach the pelvis, and in the lumbar series the anapophysis is seen projecting backwards from the base, or a little above the base of the diapophysis, its office being usually that of underlapping the anterior zygapophysis of the succeeding vertebræ and strengthening the articulation, whence Cuvier has alluded to it as an accessory articular process; but its relation to the zygapophysial joint is an occasional and not a constant character. The tenth dorsal vertebra of the Saw-toothed Seal, *Leptonyx serridens*, affords a good example of well-developed metapophyses; they are also large in most of the trunk-vertebræ of the Tapir. The anapophyses are well-developed in the anterior lumbar vertebræ of the Hare and Rabbit."—Proceedings of the Zoological Society of London, November 1848.

In a volume of Swedish Transactions, for 1848, Prof. Retzius has a paper, illustrated by woodcuts, on the modifications of some of these processes in the Class *Mammalia*. I have been recently favoured with a copy of the memoir by the learned author, bearing date 'Stockholm, 1850,' on the title-page, and received since the greater part of this paper was written and all the materials for it collected, which has been a work of some years past; but I regret that my ignorance of the Swedish language has prevented my profiting by the remarks of the estimable anatomist. In the cuts the metapophyses are called 'processus mammillares,' the anapophyses 'processus accessorii.'

[In a German translation of this memoir, kindly transmitted to me by Prof. Retzius since the present paper was in type, the following passage is added to the original:—

"(Zusatz des Verfassen; aus brieflicher Mittheilung desselben au den Uebersetzer vom 5 August 1850.—Nachdem diese Abhandlung bereits gedruckt war, hat der Verf. erfahren, dass Prof. Richard Owen in London schon i. J. 1848 (Proceedings of the Zoological Society) den *Pr. mammillares* sowohl als den *Pr. accessorii*, eigene, einfache Benennungen gegeben hat. Er nennt nämlich die ersteren oder Pr. mammillares 'Metapophyses' und die letzteren oder die Pr. accessorii 'Anapophyses,' von μετὰ *inter*, und ἀνὰ *retro*, die ersten als zwischen den Diapophyses und Zygapophyses *Owen* liegend; die letzteren als mehrentheils nach hinter gerichtet.") p. 449.]—R. O. October 27th, 1851.

† From ὑπὸ *sub*, ἀπόφυσις *processus*.

Order Bimana. Genus *Homo*.
Var. *Caucasica,* seu *Indo-Europœa.*

In the skeleton of a Frenchman, from which the figures 1 and 2 of Plate XLIV. are taken, the metapophysis first appears as a prominence (*m*) from the fore-part of the diapophysis (*d*) of the tenth dorsal vertebra: it becomes a distinct and well-marked process (*m*) from the upper and fore-part of the diapophysis of the eleventh dorsal vertebra, where the rudiment of the anapophysis (*a*) may be discerned. In the twelfth the metapophysis has increased in size and advanced nearer to the prozygapophysis (*z*, 12, fig. 2), and the anapophysis (*a*), though small, becomes distinct on this vertebra. Both processes are reduced in size in the first lumbar vertebra, in which the metapophyses (*m*) have advanced to the outer side of the prozygapophyses (*z*); while the anapophyses have descended to the back part of the base of the diapophysis. An anapophysis (*a*) becomes well-developed behind the base of the diapopophysis of the fourth lumbar: the metapophyses are reduced to tuberosities in the last four lumbar vertebræ.

In the skeleton of an Englishman, in the Museum of St. Bartholomew's Hospital, the metapophyses begin to be developed on the diapophyses of the tenth dorsal, are intermediate between the diapophyses and zygapophyses in the eleventh, are so placed in the twelfth as to overlap the posterior zygapophyses of the eleventh, and are large round tubercles upon the prozygapophyses of all the lumbars save the last.

In the skeleton of an Englishman with six lumbar vertebræ, in the Hunterian Museum, the metapophysis rises in common with the anapophysis, as a tubercle upon the diapophysis of the eleventh dorsal vertebra; the met- and an-apophyses become separated and of greater length on the twelfth dorsal, and continue equally distinct and well-developed on the first lumbar, which, from the persistent mobility of one of its pleurapophyses, might be equally regarded as a thirteenth dorsal. The metapophyses, however, subside as usual to mere tuberosities on the second lumbar, but the anapophysis continues to the fifth lumbar vertebra, in which it is most developed. It is obsolete on the last lumbar.

In the skeleton of the Irish giant, in the same museum, the metapophyses become distinct processes on the eleventh dorsal, and are repeated on the twelfth dorsal and first lumbar vertebræ: the anapophyses appear on the twelfth dorsal, and are repeated on the three first lumbar vertebræ*.

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* The common subsidence of the accessory processes on the last lumbar vertebra seems to have attracted the notice of Galen, who writes in his chapter 'De lumborum vertebris,'—"Et sane alia quædam declivis in ipsis apophysis est ab insigni exortu nervi constituta, hæc quæ interdum quidem inest omnibus, interdum vero in postremis aut exigua plane, aut prorsum nulla, sed superposita perpetuo ipsam habeat, quemadmodum et ultimæ dorsi duæ."—De Ossibus, Cap. x. Opera, fol. ed. by Renatus Charterius, Lutetiæ Parisiorum, 1679, p. 18. The *processus declives* here described by Galen in the last two dorsal and the upper lumbar vertebræ, would seem, from their defined direction, to be the 'anapophyses:' but the origin assigned to them—*παρὰ τὴν ἔκφισιν τοῦ νεύρου*—near the outlet for the nerve, does not exactly apply. Accordingly Vesalius, commenting on this passage, writes,—"Ego hunc processum in humanis vertebris nunquam reperi." And he adds,—"In

Var. *Malayana*.—In the skeleton of a male Polynesian, the metapophyses are well developed and project midway between the diapophyses and prezygapophyses on the eleventh dorsal: they rise above the prezygapophyses on the twelfth, in which there is a rudimental anapophysis, as well as a small diapophysis. The anapophysis subsides to a ridge in the lumbar vertebræ, where the diapophysis suddenly increases in length and thickness.

Var. *Papuana*.—In the skeleton of an Australian, the metapophysial tubercle, which is slightly indicated in the tenth dorsal, becomes more distinct in the eleventh, and is well developed in the twelfth dorsal. In this vertebra the anapophysis is first distinctly recognizable. In the first lumbar the metapophyses have increased in size, but do not project so freely by reason of the extension of the articular surfaces of the prezygapophyses upon the inner sides of their base. The anapophyses continue distinct. Both metapophyses and anapophyses, though small, are distinct on the second as well as the third lumbar vertebræ: the metapophyses subside on the fourth lumbar, but the anapophyses are distinctly developed in it. In the last lumbar the anapophyses appear like a part of the upper border of the base of the diapophyses, pinched up and produced backwards.

In the following observations from the lower Mammalia, *d* signifies the dorsal vertebræ, and *l* the lumbar vertebræ, in the formulæ in which their numbers are given.

Order QUADRUMANA.

In the Chimpanzee (*Troglodytes niger*), with *d*13, *l*4, the metapophysis, commencing at the eleventh dorsal, is very distinct on the twelfth dorsal, where it projects forward from above the diapophysis: in the thirteenth dorsal the metapophyses are thicker and longer than they usually are in the last dorsal of Man. In all the lumbar vertebræ they project from the upper and outer part of the anterior zygapophyses, from which they are separated by a narrow groove. There is a feeble rudiment of an anapophysis from the back part of the long and depressed diapophysis: it is longer and more distinct at the back part of the diapophysis of the last lumbar.

In a young of the great Bornean Orang (*Pithecus Wurmbii*), with *d* 12, *l* 4, the metapophysis begins to project from the anterior angle of the diapophysis in the seventh dorsal, progressively increases in size, and is advanced in position close to the anterior zygapophysis in the last dorsal, which resembles that of Man in the distinct

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simiarum igitur lumborum vertebris ad radicem transversi processus in inferiori ipsius sede, acutus conspicitur processus, rectà deorsum protensus, et sinus qui nervi nomine illic incisus est, externum latus quodammodo constituens, ac veluti intervallum cum descendente processu efformans, in quod ascendens inferioris vertebræ processus subintrat . . . . . Peculiari enim cuidam extruitur musculo, quem simiæ cum canibus communem obtinent, et quo homines inferiorem dorsi partem non æque ac illa animalia in circulum flectentes, non minus destituuntur quàm omni presentis processus signo."—De Humani Corporis Fabricâ, fol. 1555, p. 96. In the latter statement, however, VESALIUS is in error; as will be seen by whoever compares the human spine with that of the Ape or Dog, in reference to the existence of the *signa* or rudiments of the anapophyses.

development of its metapophyses; but differs in the relatively smaller size of its body and its shorter neural spine.

In a mature Sumatran Orang (*Pithecus Abelii*), with *d* 12, *l* 5, the metapophysis appears as a tubercle near the base of the prozygapophysis of the twelfth dorsal vertebra. It is equally distinct on the first lumbar, but subsides to a slight eminence on the succeeding vertebræ. The anapophysis is only distinguishable from the diapophysis upon the first lumbar vertebra; where, however, it well illustrates the homotypal relation of the diapophysis to the same processes in the antecedent dorsal and the succeeding lumbar vertebræ.

In the *Hylobates syndactyla*, with *d* 13, *l* 5, the last dorsal shows well the distinct diapophyses, metapophyses, anapophyses and zygapophyses, more especially the distinction between the prozygapophysis and the now superadded metapophysis. The diapophyses progressively increase in the first three lumbar vertebræ, whilst the anapophyses diminish and disappear on the third lumbar. The metapophysis recedes from the prozygapophysis in the last lumbar vertebra, and becomes quite distinct from it on the first sacral, in which, nevertheless, the articular surface has a nearly vertical position.

In the Silvery Gibbon (*Hylobates Leuciscus*), with *d* 13, *l* 5, both metapophysis and anapophysis become distinct on the twelfth dorsal, and diverge from each other with increase of size on the thirteenth. The anapophysis disappears in the lumbar vertebræ, but the metapophysis is retained.

In the Papas Monkey (*Cercopithecus ruber*), with *d* 12, *l* 7, the metapophyses and anapophyses are separate and distinct upon the eleventh dorsal vertebra, and also in the succeeding vertebræ to the penultimate lumbar, where the anapophysis, which is remarkable for its length in the preceding vertebræ, disappears.

In the Wrinkled Monkey (*Macacus rhesus*), the common rudiment of the meta- and an-apophysis, situated upon the diapophysis in all the dorsal vertebræ, progressively increases and elongates as the dorsal vertebræ recede from the neck, and divides into the two distinct processes upon the ninth dorsal. The metapophysial tubercle ascends upon the prozygapophysis, and is continued throughout the lumbar series; the anapophysis increasing, as in *Cercopithecus*, in the anterior lumbars so as to underlap the prozygapophysis of the succeeding vertebra, disappears in the last lumbar.

In the Entellus Monkey (*Semnopithecus Entellus*), with *d* 12, *l* 7, the metapophysis exists, as an elongated tubercle, outside the anterior zygapophysis from the eleventh dorsal to the last lumbar: the anapophysis is present from the tenth dorsal to the sixth lumbar, it is long and styliform in the intermediate vertebræ.

In the *Macacus niger*, with 13 *d* and 7 *l*, the metapophysis is developed pretty clearly on the back part of the diapophysis of the tenth dorsal, and an anapophysis projects from its lower edge; on the eleventh these parts become still more distinct; in the twelfth the metapophysis is situated upon the prozygapophysis, and the short but strong diapophysis developes from its lower edge the anapophysis; on the thirteenth the diapophysis has disappeared, but both metapophysis and anapophysis remain, the anapophysis being developed as a long pointed process. In the lumbar vertebræ the diapophyses reappear, but both the metapophyses and anapophyses are present, although they gradually diminish in size and distinctness to the sixth, and the anapophysis disappears on the last lumbar vertebra.

In the Brown Monkey (*Macacus nemestrinus*), with *d* 12, *l* 7, metapophysial and anapophysial tubercles are developed on the second and succeeding dorsal vertebræ, increasing in distinctness and size to the tenth (Plate XLV. fig. 3, $_{10}$, *m*, *a*). In the eleventh they suddenly become separate processes, and the metapophysis (*m*) developes a facet for the accessory articular surface of the posterior zygapophysis in the tenth dorsal. This additional interlocking is continued to the antepenultimate lumbar vertebra, the joint being further strengthened by the underlapping of the long-pointed anapophysis: this 'processus acutus' of Vesalius disappears on the last lumbar. The diapophysis is a rudimental ridge in the last dorsal (*d* 12), but becomes a distinct depressed sharp plate in the first lumbar and progressively increases in size, with an antroverted direction in the succeeding lumbar vertebræ.

In a Mandril (*Papio Mormon*), with *d* 12, *l* 6, an anapophysial tubercle is developed from the diapophysis of each dorsal vertebra, progressively increasing in length and distinctness to the lumbar vertebræ, in which it gradually diminishes, and is reduced in the last to a mere ridge on the upper part of the base of the diapophysis: a corresponding ridge may be recognized on the first sacral vertebra. The metapophysis is suddenly developed from the tenth dorsal, and presents an articular surface to a second articular facet on the outer side of the posterior zygapophysis.

In another Mandril the accessory joint between the zygapophysis and the parapophysis begins between the tenth and eleventh vertebræ.

In the *Papio porcarius* a rudimental metapophysis and anapophysis may be recognized in all the dorsal vertebræ after the second: they gradually increase in size to the ninth, and more suddenly in the tenth, where the metapophysis articulates with the accessory facet of the posterior zygapophysis of the ninth. The metapophysis, anapophysis and diapophysis are quite distinct processes in the last dorsal; in the lumbar vertebræ the pointed anapophyses progressively decrease, and they disappear in the last of this series.

In a Spider-Monkey (*Atèles paniscus*), with *d* 14, *l* 3, the metapophyses begin to curve inwards from the second dorsal, assume the form of a distinct plate in the tenth and eleventh, and separate themselves from the anapophyses in the thirteenth and fourteenth dorsal vertebræ: the latter processes are suppressed in the last lumbar.

In the Marimonda (*Ateles Beelzebuth*), with *d* 14, *l* 4, the tuberous rudiment of the accessory processes above the diapophysis of the middle dorsals becomes a ridge, which is produced forwards into an angular metapophysis in the eleventh dorsal. In the thirteenth it is produced to the same extent backwards into an anapophysis: in the fourteenth these processes are distinct and well-developed, but the diapophysis has disappeared; it reappears, however, in the lumbar vertebræ, from the first and second of which, nevertheless, the anapophysis continues to be developed; but this subsides in the last.

In the Capuchin (*Cebus capucinus*), with *d* 13, *l* 6, in the fifth dorsal the tubercles representing the met- and an-apophyses project distinctly, the one from the fore-part, the other from the back part of the diapophysis: they progressively increase in size and distinctness, and in the thirteenth dorsal the metapophysis has risen upon the anterior zygapophysis. The anapophysis continues to be developed to the penultimate lumbar vertebra.

In the Marmoset (*Callithrix sciureus*), with *d* 13, *l* 7, the tubercle above the diapophysis divides into a met- and an-apophysis in the ninth dorsal; in the tenth these processes diverge, and in the eleventh become quite distinct; they continue to increase in length to the fifth lumbar; the anapophysis then diminishing, and being suppressed in the last lumbar.

In the Black-fronted Lemur (*Lemur nigrifrons*), with *d* 12, *l* 7, the metapophysis begins to be developed in the middle dorsal vertebræ, and in the tenth projects from above the diapophysis: this disappears in the eleventh dorsal, and the metapophysis is on the outside of the anterior zygapophysis. From this vertebra a well-marked anapophysis is developed, and is continued from all the succeeding vertebræ. The diapophysis reappears upon the first lumbar, and increases in length and breadth as these approach the sacrum.

In a Ring-tailed Lemur (*Lemur Catta*), with *d* 13 and *l* 7, and in a Ruffed Lemur (*Lemur Macauco*), with *d* 12, *l* 7, the division of the 'transverse process' into di-, met- and an-apophyses is well shown in the tenth dorsal, and in the succeeding vertebræ the three processes are distinct and remote.

In the Indri (*Lichanotus Indri*), with *d* 12, *l* 9, the diapophyses of the dorsals support a metapophysial tubercle, which grows as the diapophyses diminish, and seems to take their place in the eleventh and twelfth dorsals: in the twelfth the metapophysis rises from above the prozygapophysis and is continued backwards upon a well-developed anapophysis which commences at once in that vertebra, and continues to be developed though decreasing in length to the penultimate lumbar inclusive. The metapophyses, which are prominent in the anterior lumbar vertebræ, gradually subside as they approach the sacrum. The diapophysis has a low rough tubercle in the first lumbar vertebra, which is developed into a depressed plate, increasing in length and breadth as it approaches the sacrum.

In the Slow Lemur (*Stenops gracilis*), with *d* 14, *l* 9, a metapophysial tubercle is developed from above the diapophysis from the first to the twelfth dorsal vertebra: in the thirteenth it takes the place of the diapophysis, and in the fourteenth it extends forwards and presents an articular surface to a facet on the outer side of the post-zygapophysis of the thirteenth vertebra. The metapophysis has the same disposition and connections throughout the lumbar series, where it is above and distinct from the diapophyses, which are serial repetitions of the base supporting the anchylosed ribs on the first lumbar vertebra.

Order Carnivora.

In the Lion (*Felis Leo*), with *d* 13, *l* 7, the common base of the met- and an-apophyses appears as a strong ridge above the diapophysis of the tenth dorsal; the ridge increases in the eleventh, divides into a large and strong metapophysis and anapophysis in the twelfth; both of these increase in size in the thirteenth dorsal. The metapophyses are continued throughout the lumbar region: the anapophyses diminish to short and thin styliform processes, underlapping the prozygapophyses of the first four lumbars, and becoming rudimental in the rest. The prozygapophyses are distinctly developed in all the dorsal vertebræ anterior to that in which the metapophyses are superadded to them.

In the Puma (*Felis concolor*), with the same vertebral formula, the common accessory tubercle indicates the anapophysis by its backward production from above the diapophysis of the ninth dorsal (Plate XLV. figs. 5 and 6, *a*): the anapophysis grows longer in the tenth (fig. 5, *a*); and in the eleventh the metapophysis (*m*) suddenly shoots upwards and forwards, the anapophysis (*a*) diverges from it backwards, underlapping the metapophysis of the next vertebra, and both processes far surpass the diapophysis (*d*) in size, which clearly, however, coexists with them. It disappears in the thirteenth vertebra, in which both ana- and met-apophyses have increased in length; and the only question that remains with regard to the ‘transverse process’ (*d*) of the following vertebræ is, whether it includes the diapophysis at its base, or consists solely of the connate pleurapophysis. The eleventh vertebra permits of no doubt as to the distinctness of the diapophysis (*d*) from the two larger superadded processes (*m* and *a*), and, in fact, a rudiment of the diapophysis may be recognized above the costal pit in the last dorsal. Fig. 6 shows the prozygapophyses (*z*) existing, as in all the anterior dorsals, independently of the metapophyses*: fig. 7 shows them coexisting (*z*) with metapophysis (*m*), anapophysis (*a*), and diapophysis (*d*). The neural spine in this vertebra, which is the centre of motion of the spine, is low and nearly vertical; the longer spines of contiguous vertebræ converge to it.

In the *Hyæna crocuta*, with *d* 15, *l* 5, the anapophyses begin to be distinct, and to project backwards in the thirteenth dorsal, underlap the prozygapophyses in the first three lumbar, and subside on the penultimate lumbar vertebra.

In the Wolf (*Canis Lupus*) and Dog, with *d* 13, *l* 7, the metapophyses begin to be developed on the eighth dorsal, and are continued throughout the lumbar series: the anapophysis projects backwards in the eleventh dorsal, and subsides to a mere ridge in the penultimate lumbar. In the Fox they begin to be developed on the seventh dorsal, and are reduced to mere tubercles on the third lumbar. In the Civet (*Viverra Civetta*) and the Genette (*Viverra Genetta*) the anapophyses begin to be developed on the tenth dorsal, and continue to the penultimate lumbar vertebra.

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* ‘*Apophyses antobliques*,’ Straus-Durckheim.

In the Otter (*Lutra vulgaris*), with *d* 14, *l* 5, the metapophyses begin to be developed on the twelfth dorsal vertebra, and are continued throughout the lumbar series; they are low and obtuse. The anapophyses commence at the eleventh vertebra, and are continued to the penultimate lumbar.

In the Sable (*Mustela zibellina*), with *d* 14, *l* 6, the anapophyses are present from the ninth dorsal to the penultimate lumbar inclusive.

The Kinkajou, *Cercoleptes caudivolvulus*, with the same number of true vertebræ as the Sable, has the same disposition of the anapophyses.

In the *Mydaus meliceps*, with *d* 14, *l* 6, anapophyses are present only on the two last dorsal and first lumbar vertebræ: whilst in the Badger (*Meles Taxus*), with *d* 15, *l* 5, they are present on the first three lumbar vertebræ.

In the labiated Bear (*Ursus labiatus*), with *d* 15, *l* 5, the met- and an-apophyses are distinct on the twelfth dorsal, diverge and increase on the succeeding dorsals, the metapophyses continuing throughout the lumbar series, the anapophyses, after underlapping the prozygapophyses of the first and second lumbar, rapidly subsiding.

In the Saw-toothed Seal (*Leptonyx serridens*), with *d* 15, *l* 5, the metapophyses commence as tubercles outside the prezygapophysis on the second dorsal, are distinct on the third dorsal, pass on the fore-part of the diapophysis in the fourth, and continue rudimental as far as the tenth dorsal, on which they are well and distinctly developed (Plate XLVI., fig. 8, *m*); they again pass upon the outside of the prozygapophysis in the eleventh and twelfth dorsals, and so continue throughout the lumbar, sacral, and anterior caudal vertebræ. The anapophyses are mere rudimental projections from the back part of the diapophysis (fig. 8, *a a*).

Order Rodentia.

In the skeleton of the common Squirrel (*Sciurus vulgaris*), with *d* 12, *l* 6, may well be discerned the progressive metamorphosis, in the last six dorsal vertebræ, of the common accessory tubercle upon the diapophysis into the metapophysis and anapophysis, which distinctly coexist with the diapophysis in the ninth dorsal: the diapophysis subsides to a feeble ridge in the three following dorsals, but reappears and rapidly increases in the lumbar series; in the last two of which the anapophyses are suppressed.

In the Malabar Squirrel (*Sciurus maximus*), with *d* 13, *l* 6, the ridge above the diapophysis of the seventh dorsal rapidly expands in the succeeding ones, divides in the tenth into metapophysis and anapophysis, which become more distinct in the eleventh, and are so continued throughout the lumbar series.

In the Marmot (*Arctomys Marmotta*), with *d* 12, *l* 7, the accessory tubercle appears upon the diapophysis of the ninth dorsal, and divides in the tenth, in which the diapophysis is suddenly shortened: the metapophysis and anapophysis are distinct in the eleventh dorsal, and so continue to the penultimate lumbar.

In the *Hydromys chrysogaster*, with *d* 14, *l* 7, the common tubercle divides on the twelfth dorsal, and the met- and an-apophyses are distinct on the five following vertebræ.

In the Rat (*Mus rattus*), with *d* 13, *l* 6, the common tubercle, which first appears on the sixth dorsal, divides into metapophysis and anapophysis in the ninth. The anapophyses become obsolete in the last two lumbar vertebræ.

In the Cape-Jerboa (*Helamys capensis*), with *d* 12, *l* 7, the diapophyses of the first dorsal vertebra are unusually long and strong: the anapophysis begins to be developed from the back part of the diapophysis of the eighth dorsal, and the metapophysis from the front part of that of the ninth; in the tenth dorsal (Plate XLVI., fig. 9) both metapophysis (*m*) and anapophysis (*a*) are distinct from the diapophysis (*d*). In the twelfth dorsal the metapophysis ascends upon the prozygapophysis, the anapophysis has increased in length, and the diapophysis is retained. Both ana- and met-apophyses are of considerable length in the lumbar region, except in the two last vertebræ.

The progressive development of the accessory tubercle, and its transformation into metapophysis and anapophysis, are well exemplified in the last five dorsal vertebræ of the Beaver (*Castor fiber*).

In the Porcupine (*Hystrix cristata*), with *d* 15, *l* 4, the accessory tubercle begins to be developed upon the fourth dorsal, and, progressively increasing, it divides in the eleventh into metapophysis and anapophysis. The distinction of these from the diapophysis which supports the last floating rib is well-marked in the last dorsal vertebra. In the lumbar vertebræ the anapophyses strengthen the joints by underlapping the metapophyses, but both processes become rudimentary in the last lumbar vertebra.

In the Coypu (*Myopotamus Coypus*), with *d* 13, *l* 6, the common tubercle appears upon the sixth dorsal; progressively expands, and in the twelfth divides into metapophysis and anapophysis: the latter subsides in the last lumbar vertebra, but the metapophysis is continued along the sacral and a great part of the caudal region, continuing long after the true zygapophyses have disappeared.

In the Paca (*Cœlogenys Paca*), with *d* 13, *l* 6, the common rudiment of the met- and an-apophyses extends above the diapophysis of the seventh dorsal as a broad ridge; in the eighth the ridge is bilobed, in the ninth the lobes diverge; in the tenth and eleventh they become distinct processes: the anapophysis disappears in the last lumbar, but the metapophysis is retained in all the lumbars.

In the Hare (*Lepus timidus*), with *d* 12, *l* 7, both metapophysis and anapophysis appear abruptly on the ninth dorsal: the metapophyses progressively increase to the second lumbar, and are continued, remarkably developed, throughout that region: the anapophysis becomes a low long ridge in the last dorsal, and continues, as such, with a slight posterior projection to the antepenultimate lumbar; it is rudimental on the penultimate one, and disappears on the last lumbar. The last dorsal and the three first lumbars are remarkable for their long hypapophysis.

In the *Lagotis Cuvieri*, with *d* 12, *l* 7, the common potential base of the dia-, ana- and met-apophyses divides more equably than usual into the three processes; and perhaps no better example can be had of their real distinctness from one another and from the zygapophyses, than that which the ninth dorsal (Plate XLVI. fig. 10, 9, *a, m, d, z, z'*) affords; the neural arch seems studded with processes, the nature of which is perfectly comprehended by the comparisons which are given in the present Memoir. In the tenth dorsal the anapophysis (*a*) and metapophysis (*m*) increase in size, especially the latter, which is now closer to the prozygapophysis. The anapophyses are remarkable for their length and slenderness in the lumbar vertebræ (*ib.* 2 and 3, *a a*). The long and slender anapophyses are equally remarkable in the *Lagostomus*, to judge from the figure of the skeleton in the Linnæan Transactions for 1828, vol. xvi. pl. 9, but as those processes had not at the time been defined in the Rodentia no notice is taken of them in the text.

The Capybara (*Hydrochœrus capybara*), with *d* 14, *l* 6, gives one of the best illustrations of the distinction of the metapophyses (*Apophyses antobliques* of Straus-Durckheim) from the true anterior oblique processes. The metapophysis may be distinguished as a tubercle above the diapophysis from the third to the eighth dorsal vertebræ inclusive: at the eighth and ninth it (Plate XLVII. fig. 11, 8 and 9, *m*) begins to project forwards; in the tenth (fig. 11, 10, *m*,) it is longer than the diapophysis (*d*) that supports it; in the eleventh the metapophysis (*ib.* 11, *m*) begins to shift its position and rises half-way between the diapophysis and the prozygapophysis (*z*); in the twelfth dorsal it rises behind the prozygapophysis; in the fourteenth dorsal it has got above that process and the articular surface begins to ascend upon the inner side of its base: the change of place and aspect of that surface is completed in the lumbar series. The anapophysis separates itself from the metapophysis in the eleventh dorsal (*ib.* 11, *a*), and progressively increases to the penultimate dorsal, beyond which it decreases, and it disappears on the fifth lumbar. The diapophysis is suppressed in the last four dorsal vertebræ.

Order Insectivora.

In the Hedgehog (*Erinaceus europœus*) the metapophysis commences as a slight tuberosity above the diapophysis of the second dorsal, becomes a distinct process in the third, projects outwards and forwards freely above the diapophysis in the fourth and fifth dorsals, ascends to the outside of the base of the prozygapophysis in the sixth, and continues there, inclining a little more upwards, and with increased breadth in the remaining dorsals, and in the lumbar vertebræ: also along the caudal vertebræ as far as the tenth, where the zygapophyses disappear and the metapophyses alone are present. There are no anapophyses.

The vertebral characters of the Tenrees (*Centetes*) resemble in these respects those of the Hedgehogs.

In the Moles (*Talpidæ*) short anapophyses are developed from some of the anterior lumbar vertebræ.

In the Shrews (*Soricidæ*) they are somewhat better marked; the anapophyses are continued from the penultimate dorsal to the third lumbar vertebræ in the great Indian species (*Sorex myosurus*); whilst in the *Cladobates ferrugineus* they underlap the metapophyses of the succeeding vertebra in the last dorsals and in all, save the last lumbar vertebræ. The diapophyses in both *Talpidæ* and *Soricidæ* resemble those in the *Erinaceidæ*.

Order MARSUPIALIA.

In the Thylacine (*Thylacinus Harrisii*), with *d* 13, *l* 6, the anapophysis appears first upon the ninth dorsal, as a pointed process projecting from the back of the diapophysis; it increases in size and ascends in position on the tenth; is large, obtuse, and underlaps the metapophysis of the succeeding vertebra in the last two dorsals; progressively diminishes in the lumbar vertebræ, and disappears on the fourth of that series. The metapophysis is developed abruptly on the tenth dorsal external to the prozygapophysis, increases in size in the following dorsals, diminishes in the lumbar vertebræ, but is present throughout the series as a strong obtuse process: it is continued, also, through a great part of the caudal series, in which the zygapophyses become obsolete at the eighth vertebra.

In the Ursine Dasyure (*Dasyurus ursinus*), with *d* 13, *l* 6, both anapophyses and metapophyses commence at the eleventh dorsal: the anapophyses increase to the second lumbar, diminish in the two following, and disappear in the fifth. They underlap the metapophyses of the first three lumbar vertebræ. The metapophyses are continued throughout the sacral and a great part of the caudal region, in which the zygapophyses cease to be developed at the eighth vertebra.

The diapophyses are not obliterated in the last dorsal vertebræ, which renders their serial homology distinctly traceable along the lumbar region.

In the Wombat (*Phascolomys vombatus*), with *d* 15, *l* 4, the metapophysis (*m*) rises suddenly from the outside of the prozygapophysis (*z*) of the twelfth dorsal (Plate XLVII. fig. 12, D 12); increases in length to the second lumbar (L 2), diminishes by degrees to the second sacral; and is rudimental in the following sacral and caudal vertebræ. A rudiment of the anapophysis (*a*) is first discernible on the eleventh dorsal: the process gradually increases to the last dorsal (*a* D 15), diminishes in the lumbar, and disappears in the last of that series. In the skeleton showing the above modifications, the sutures between the short straight pleurapophysis (*pl*) and diapophysis (*d*) of the first lumbar vertebra (L 1) still in a great degree remain; the anchylosis is only partial; and the proportion of the autogenous and exogenous elements of the so-called 'transverse process' is plainly demonstrated. The diapophysis, moreover, is not suppressed on the last dorsal vertebra as in some of the *Quadrumana*, *Carnivora* and *Rodentia*. The serial homology of the transverse processes of the lumbar vertebræ is here, therefore, manifested in the most unequivocal way; both metapophyses (*m*) and anapophyses (*a*) coexist with diapophyses (*d*) in the last four dorsal and the first three lumbar vertebræ. So that, whether the metapophysis or the anapophysis be the part called 'tubercle' by some Anthropotomists, neither of them is in the lumbar vertebræ, the process named 'transverse' in the thoracic vertebræ; that process, to which I restrict the name 'diapophysis,' is continued distinctly into the lumbar region, and is there lengthened out by a superadded 'pleurapophysis,' which is ossified from a distinct centre in the Wombat, but is not so ossified in the human skeleton, in which only a mere epiphysis, like that at the extremity of the spinous process, is superadded to the end of the transverse process of the lumbar vertebræ*.

In the skeleton of the Great Kangaroo (*Macropus major*), with *d* 13, *l* 6, both met- and an-apophyses commence, suddenly, on the twelfth dorsal, the former (*m*) as broad compressed plates from the anterior two-thirds of the side of the neural arch, the latter (*a*) as short processes from the hinder border of the same arch. The metapophyses (*m*) increase to the first lumbar, and after the second decrease to the sacral vertebræ: they again begin to increase in the caudals and attain great size in the third to the seventh of that series, in which latter vertebræ the zygapophyses have disappeared: but the metapophyses (see Plate LIII. fig. 62, A, C, *m m*) are continued to near the end of the tail. The anapophyses (*a*) increase to the second lumbar, and rapidly decrease after the third; they are obsolete in the last lumbar.

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* The author of the article 'Skeleton' in the Cyclopædia of Anatomy and Physiology, Part XXXV., March 1839, cites, p. 628, the following passage from my work on the Archetype and Homologies of the Vertebrate Skeleton:—"Each of the five succeeding segments is represented by the same elements coalesced, that constitute the so-called dorsal vertebra; they are called lumbar vertebræ; they have no ossified pleurapophyses," with the following comment:—"Professor Owen's 'pleurapophysis' is the rib or costal appendage of his typical vertebra. While he states, therefore, that the lumbar vertebra has no pleurapophysis, he means that it has no rib or costal piece. This oversight (which, with all respect, I believe it to be) has arisen from the evident error of mistaking the lumbar transverse process as being the counterpart or homologue of the dorsal transverse process, which, if such were the case, would leave the lumbar vertebra without a rib." The passage so commented on is taken from a 'Section' of my work treating of the specialities of the Human Skeleton; in the 'Section' treating on lumbar vertebræ in general, I state,—"The lumbar vertebræ, which in some mammals show, in the fœtal state, distinct rudiments of pleurapophyses more minute than those in the neck, have them soon anchylosed to the extremities of the diapophyses, which are thus elongated," p. 94. No one proposing fairly to criticise my opinions on the transverse process of a lumbar vertebra in general, ought to have represented them by a quotation of a description of the lumbar vertebra of a particular species. But taking the passage upon the human skeleton, as cited above, the conclusion of the Critic that I "leave the lumbar vertebra without a rib," can only be sustained by the omission of a word in that passage. What I do state is, that, in them, "they have no *ossified* pleurapophyses." Now in a previous part of the work quoted from, it is shown, that a vertebral element may exist in three states, 'fibrous,' 'cartilaginous,' 'osseous,' and that its absence was not to be assumed merely because it had not passed into the bony stage. I have never met with a human lumbar vertebra showing the transverse process lengthened out by a distinct autogenous ossification, meriting, like that of the Wombat, Plate XLVII. fig. 12, L 1, to be regarded as a pleurapophysis: the whole is an exogenous outgrowing diapophysis, with a minute epiphysis, which begins to be ossified about the age of sixteen, and is comparable in my opinion with that at the extremity of the metapophysis and neural spine. As to the opinion that the transverse process of the dorsal vertebra is homologous with the 'tubercle' of the lumbar vertebra, whether by 'tubercle' is meant the metapophysis or the anapophysis, I need only refer to those skeletons of mammalia, in which, as in the Wombat, Kangaroo and Dasyure, the true diapophysis is not suppressed on the last dorsal vertebra, in order to ensure a conviction in every impartial observer that the exogenous part of the transverse process of the lumbar vertebra is the serial homologue or tallying part with the diapophysis, or part of the transverse process supporting the rib, of the dorsal vertebræ.

The smaller *Macropus Parryi*, with the same vertebral formula, resembles the Great Kangaroo in regard to the accessory processes; except that the anapophyses are relatively smaller and begin in the eleventh dorsal (Plate XLVII. fig. 13, D 11, *a*) upon the diapophysis (*d*); passing in the twelfth to the back part of the neural arch; they underlap the metapophyses (*m*) of the first four lumbar vertebræ and become mere rudiments in the two last (*ib.* L 5 and 6, *a*). In both species of Kangaroo the diapophyses (*d*) continue to be developed in the last dorsal vertebræ, rendering the homologies of those of the lumbar series unmistakeable.

In a *Perameles lagotis*, with *d* 13, *l* 6, the metapophysis begins at the ninth dorsal vertebra, rapidly increases to the first lumbar, and continues large, though slightly decreasing in the last two lumbars: they are continued along the sacrum and a great part of the caudal vertebræ. There are no anapophyses in this species.

Order MONOTREMATA.

The metapophyses are double, one behind the other, in the form of low tubercles, on each side of the neural arch of the third, fourth, and fifth dorsal vertebræ of the *Ornithorhynchus paradoxus*; they become single on the sixth dorsal, and gradually increase in size to the twelfth: beyond this vertebra they increase in antero-posterior extent chiefly, and thus attain their maximum of size in the last dorsal and the two lumbar vertebræ; they are continued throughout the sacral and to near the end of the caudal region. A rudiment of the anapophysis is discernible on the fourteenth, the fifteenth and sixteenth dorsal vertebræ, projecting backwards over the hole for the nerve at the side of the neural arch.

Order UNGULATA.

Suborder *Artiodactyla*.

Tribe *Ruminantia*.

In the Musk-Deer (*Moschus moschiferus*), with *d* 14, *l* 5 (Plate XLVIII. fig. 14), a distinct metapophysis (*m*) begins to be developed above the diapophysis of the second dorsal, is midway between this and the prozygapophysis in the tenth dorsal, rises upon the outside of the prozygapophysis on the eleventh, attains its greatest length in the twelfth, and becomes thicker and more obtuse in the remaining dorsals and in the lumbar vertebræ. There are no anapophyses.

In the skeleton on which these observations were made, there is a peculiarity that well illustrates the serial homology of the diapophyses of the dorsal and lumbar regions. The tubercle disappears in the penultimate pair of ribs, and the diapophysis is reduced in the thirteenth dorsal vertebra to a short rough tuberosity (*d'*): but in the last pair of ribs the tubercle with its articular surface reappears, and the diapophysis (*d*) resumes its normal size and articulation with the rib, which inclines forwards at its commencement. In the first lumbar vertebra the diapophysis (*d*) suddenly increases in length and breadth, which increase is doubtless due to the ossified and coalesced rudiment of a rib (*pl*).

In the Meminna (*Moschus meminna*), with *d* 13, *l* 7, the metapophysial tubercle appears above the diapophysis of the anterior dorsals, projects as a distinct process midway between the diapophyses and prozygapophyses of the seventh to the tenth dorsals inclusive; gets upon the prozygapophysis of the succeeding dorsals and anterior lumbars, and subsides in the penultimate lumbar vertebra. The tubercle has disappeared on the tenth rib, and does not reappear in those that follow: but the diapophysis continues on the last four dorsal vertebræ, increasing in length upon the last two, and plainly showing the nature of the longer diapophyses in the lumbar region.

In the Elk (*Alces Americana*), with *d* 13, *l* 6, the metapophysial ridge becomes distinctly developed upon the diapophysis of the eighth dorsal, is a tubercle on the ninth, forms a process exceeding in length the diapophysis in the tenth and eleventh dorsals, and subsides to a tuberosity again in the twelfth and succeeding vertebræ, where its position has changed from the diapophysis to the zygapophysis. There is a slight trace of an anapophysis in the last lumbar vertebra.

In the Equine Antilope (*Antilope equina*), with *d* 13, *l* 6, the metapophysis is developed from the fore-part of the diapophysis of the second to the ninth dorsals inclusive, where it begins to be transferred to the outer side of the prozygapophyses, from which part it projects in the last four dorsals, and in all the lumbar vertebræ. There is a short anapophysis in the last two dorsals, but not in any of the lumbar vertebræ.

In the Gnu (*Catoblepas Gnu*), with *d* 14, *l* 6, there are no anapophyses; the metapophyses resemble those in the Equine Antilope.

In the Common Ox (*Bos Taurus*), with *d* 13, *l* 6, the metapophysis, beginning as a rudimentary tubercle at the anterior dorsals, increases in size in the tenth, eleventh and twelfth dorsals, in which it is transferred from the diapophysis to the prozygapophysis.

In the Aurochs (*Bison Europæus*), with *d* 14, *l* 5, the metapophysis is most distinct on the ninth, tenth and eleventh dorsals, in which it ascends to the prozygapophysis.

In the Giraffe (*Camelopardalis Giraffa*), with *d* 14, *l* 5, the metapophyses commence as distinct and well-marked tuberosities above the diapophyses of the second dorsal; subside at the eighth, and are rudimental to the thirteenth; they recommence as distinct processes at the fourteenth dorsal, where they project forwards on the outer side of, but quite distinct from, the prozygapophyses; ascend upon those processes in the first lumbar, and so continue throughout the lumbar series. There are no anapophyses.

In the Camel (*Camelus Bactrianus*), with *d* 12, *l* 7, the metapophysial tubercle is developed from the diapophysis in the eleven anterior vertebræ, and passes upon the prozygapophysis in the twelfth, continuing in that position throughout the lumbar series. There are no anapophyses.

In the Vicugna (*Auchenia Vicugna*) the metapophysis is between the diapophysis and prozygapophysis, from the fourth to the tenth dorsal, and passes upon the prozygapophysis at the eleventh dorsal. There are no anapophyses.

Tribe *Non-Ruminantia*.

In an Indian Wild Boar (*Sus scrofa*), with *d* 13, *l* 6, the metapophysis commences as a tuberosity upon the diapophysis of the middle dorsal vertebræ, projects forwards midway between the dia- and prozyg-apophysis in the tenth, passes upon the prozygapophysis of the eleventh dorsal, and is continued in that position throughout the lumbar series. There are no anapophyses.

In the Peccari (*Dicotyles labiatus*), with *d* 14, *l* 6, the metapophysis begins to be developed at the third dorsal, and increases in length to the eleventh, beyond which it is transferred from the dia- to the prozyg-apophysis.

In the Hippopotamus (*Hippopotamus amphibius*), with *d* 15, *l* 4, a metapophysial ridge is developed above the diapophysis of the eighth dorsal, changes its position and shape in the succeeding vertebræ, and in the eleventh has passed, as a tuberosity, upon the prozygapophysis. It retains these characters throughout the rest of the dorsal and the lumbar series. There are no anapophyses.

Suborder *Perissodactyla*.

In the Horse (*Equus caballus*), with *d* 19, *l* 5, the metapophysis, commencing as a tuberosity above the diapophysis, passes gradually from that part to the outer side of the prozygapophysis, which it finally attains in the seventeenth dorsal vertebra, and continues in the same place throughout the lumbar series. There are no anapophyses.

In the Sumatran Rhinoceros (*Rhinoceros Sumatranus*), with *d* 19, *l* 3, the metapophysis begins, as a tuberosity, above the diapophysis of the fourth dorsal, projects distinctly forward from the eighth, and continues so projecting, and slightly increasing in length, to the seventeenth; in the eighteenth it begins to approach the zygapophysis, and gets outside of it in the nineteenth; and so continues, reduced to a tuberosity, in the lumbar vertebræ. There are no anapophyses. The back part of the diapophysis of the last lumbar presents a distinct articular process for a corresponding one on the fore-part of that of the first sacral vertebra.

In the Sumatran Tapir (*Tapirus Malayanus*), a very distinct metapophysis projects upwards and forwards from the fore-part of the transverse process of the third dorsal; it becomes a thicker and lower tuberosity above the diapophysis on the four succeeding vertebræ: then again becomes prominent, with a rounded anterior edge in the succeeding dorsals, projecting from the fore-part of the diapophysis in the four last dorsals, where that process is raised above and is distinct from the rib, and projects upwards and outwards. In the lumbar region the metapophysis is very distinct, and does not pass upon the prozygapophysis until the last lumbar*. There are no anapophyses.

Tribe *Proboscidia.*

In the Asiatic Elephant (*Elephas Asiaticus*), with *d* 19, *l* 4, the metapophyses present a character different from that in all other *Ungulata*; they are first recognizable as an obtuse point projecting forwards from the fore-part of the diapophysis of the sixteenth dorsal vertebra; in the seventeenth the metapophysis has assumed a subdepressed quadrate shape, and projects obliquely outwards and forwards from the outside of the prozygapophysis: in the eighteenth dorsal it extends forwards, and overlaps an anapophysis developed from the back part of the diapophysis of the seventeenth dorsal, and these accessory joints continue between the succeeding vertebræ as far as the first and second lumbars. The anapophyses have disappeared in the third and fourth lumbars, in which the metapophyses are reduced to short thick tuberosities, still projecting, not from above, but quite external to, the prozygapophyses. The metapophyses are continued along the sacral and caudal vertebræ, and in a large proportion of the latter supersede the prozygapophyses.

Order SIRENIA.

In the Dugong (*Halicore indicus*) there is a feeble rudiment of a distinct metapophysis on the outer side of the prozygapophysis of the fifth dorsal; but the homotypes of the metapophyses are so little developed in the preceding vertebræ, that the change of aspect of the articular surface seems to be due exclusively to a gradual change of position in the anterior zygapophyses themselves.

Order CETACEA.

In the small Bottlenose Whale (*Delphinus Tursio*), the metapophysis (*m*) begins to project from the fore-part of the diapophysis (*d*) of the third dorsal, increases in length in the fourth (Plate XLVIII., fig. 15, D 4), and is gradually transferred in the sixth (D 6) and seventh (D 7) dorsals to the outer side of the prozygapophyses (*z*): in the following vertebræ it seems to take their place, and to occasion a reversing of the usual relative position of the zygapophysis; for whereas in the cervical and anterior dorsal vertebræ the anterior zygapophyses are overlapped, as in other mammals, by the posterior zygapophyses, in the succeeding dorsals, beginning with the seventh, the posterior zygapophyses seem to be overlapped and concealed by the anterior zygapophysis. But this is not the case; the appearance is due to the place of the prozygapophyses (*z*) being taken by the metapophyses (*m*). These latter processes, in fact, continue after the articular surface has ceased to be developed, and after the entire disappearance of the posterior zygapophyses, to project forwards from the thirteenth dorsal to the sixth lumbar vertebra inclusive; beyond which the neural arch is devoid of all exogenous processes, save the spine, until the middle caudal vertebræ, where rudiments of the metapophyses again reappear.

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* STRAUS-DURCKHEIM's term 'anapophyse antoblique,' applied to these processes in the Cat, would be quite inappropriate and unintelligible if applied to their homologues in the Tapir.

In the common Dolphin (*Delphinus Delphis*), Plate XLVIII. fig. 16, the metapophysis (*m*) begins abruptly, as a long well-marked process, from the fore-part of the diapophysis (*d*) of the fourth dorsal (D 4); progressively approximates and attains the outside of the prozygapophysis in the eighth dorsal (D 8), performs the function of an articular process as far as the sixth lumbar, clamping, as it were, the sides of the back part of the base of the spine of the antecedent vertebra, disappears in the next dozen lumbar vertebræ, and reappears in the caudal vertebræ at the fore-part of the base of the spine.

There are no anapophyses in the *Cetacea*. With respect to the metapophyses, CUVIER, in his description of the vertebræ of the Dolphin, confounds them, as STRAUS-DURCKHEIM has done in the Cat, with the true zygapophyses. He writes,—"The last cervical and the six first dorsals have their articular processes joined together by horizontal facets, of which the anterior looks upwards. At the sixth they begin to be oblique, at the seventh they are nearly vertical, the anterior looking inwards*." But in the figure which he refers to, of the fourth dorsal vertebra of the *Delphinus Delphis*, the accurate artist, M. LAURILLARD, represents the metapophyses as distinct from the prozygapophysis or anterior articular process, although less so than it is in nature; and it is incontestably the progressive development of this superadded process which gives rise to the change of position of the articular surface of the connate prozygapophysis: and the metapophysis continues to be developed, as the figures in the 'Ossemens Fossiles' demonstrate, long after the articular process or any articular surface has ceased to exist†.

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* Ossemens Fossiles, Ed. 1823, tom. v. pt. i. p. 303, pl. xxiii. figs. 25—29.

† This fact is clearly recognized by Professor STANNIUS, in his 'Vergleichende Anatomie der Wirbelthiere,' 8vo., p. 345, where he describes the 'metapophyses' as 'processus accessorii.'

Order Bruta (*Edentata*, Cuv.).

The exogenous processes of the vertebræ present their greatest and most complex developments in this order, but by no means with that degree of uniformity which renders their modifications characteristic of some of the preceding Orders. The two extremes in the degree of development are, in fact, presented by the much-diversified families of the present extraordinary group of mammals.

The spinous processes are almost obsolete in a great part of the unusually long dorso-lumbar region of the Two-toed Sloth (*Bradypus didactylus*), and the metapophyses would be hardly recognizable if their modifications had not been previously traced in other mammals. The first indication of them is seen in the penultimate dorsal vertebra, where they appear as angular productions from the upper and fore-part of the diapophyses: in the last dorsal they have advanced clear of the diapophysis to the outer side of the prozygapophysis, the articular surface of which begins to ascend upon them; and they continue, as low and long tuberosities, above the prozygapophyses, throughout the lumbar region. In the sacral vertebræ they are obsolete. No anapophyses are developed in this species of Sloth[*].

[*] In assigning, with Cuvier, this formula to the dorsal region of the spine, I have been guided by characters which have appeared to me more demonstrative of the homology of the eighth and ninth vertebræ of the Ai, with the last two cervicals of other mammals, than the sometimes persistent freedom of their short pleurapophyses are of their homology with the first two dorsals. The penultimate cervical vertebra, for example, has a well-marked and constant character in most mammals in the greater antero-posterior extent of its anchylosed pleurapophysis; and I find this character repeated in the eighth vertebra, counting from the atlas, in the Three-toed Sloth. Subjoined are the chief particulars which are noticeable in the cervical region of the skeleton of the mature specimen of that species in the Museum of the Royal College of Surgeons.

The hind-part of the bodies of the second to the sixth cervical vertebræ inclusive, are produced backwards and underlap the fore-part of the body of the succeeding vertebræ. The transverse process of the atlas is imperforate' but the base of the neural arch is pierced by the vertebral artery anteriorly and by the cervical nerve posteriorly. The spines of the cervical vertebræ are moderately and more equally developed than in other mammals; that of the dentata being little larger than the rest. The pleurapophysial part of the transverse process of the eighth cervical is anchylosed, and is more extended antero-posteriorly than in the preceding cervicals, in which respects it resembles the sixth cervical vertebra in ordinary quadrupeds. The pleurapophysial part of the transverse process of the ninth cervical is free, and is more extended in the direction of its length, but is very short compared with the homologous part of the succeeding vertebra. The slender neck and head of this little rib joining the fore-part of its centrum occasions the perforated character of the ninth, as in the antecedent cervical vertebræ. In the fourth cervical, however, the vertebral artery perforates the right transverse process, but only grooves the left on its anterior part. The transverse processes of the second and third cervical vertebræ are both imperforate.

The homology of the vertebra succeeding the ninth with the first dorsal of the Unau and of other mammals, is demonstrated by the junction of its rib with the manubrium by the superadded hæmapophysial element, which is here, however, ossified and anchylosed with both its pleurapophysis and the manubrium. Nine pairs of ribs directly articulate to the sternum, which consists of eight bones; these are compressed and progressively increase in depth. The hinder ones are divided into a larger posterior and a smaller anterior part, between which are four articulated facets on each side for the bifurcated extremities of two of the ossified hæmapophyses[†].

[†] Proceedings of the Zoological Society, 1849, p. 146.

In the Ai (*Bradypus tridactylus*), with *d* 16, *l* 3, both met- (*m*) and an- (*a*) apophyses, Plate XLIX. fig. 17, are present, and the former are more distinctly developed than in the Unau: they are, however, restricted, as in that species, to a very few vertebræ. The metapophysis (*m*) is first developed as a distinct, though small obtuse conical process from the fore-part of the diapophysis (*d*) of the penultimate dorsal vertebra (D 15); it increases in size and approaches the prozygapophysis (*z*) of the last dorsal (D 16); ascends upon the outside of that process, and becomes more obtuse in the first (L 1) and following lumbar vertebræ.

In the *Orycteropus capensis*, with *d* 13, *l* 8, an accessory tubercle is developed upon the diapophysis of the seven anterior dorsal vertebræ, which divides near the eighth into metapophysis and anapophysis. These progressively increase and diverge from one another in the succeeding dorsals, and in the first lumbar vertebra the metapophysis projects upwards, outwards and forwards upon the outside of the anterior zygapophysis; whilst the anapophysis extends backwards from the back part of the diapophysis, which it equals in length. The anapophysis decreases in size in the following lumbar vertebræ and disappears in the last*; the metapophysis also decreases in size, but is continued throughout the lumbar series and along part of the sacral. The transverse processes of the three anterior sacrals join the ilia; those of the three posterior ones coalesce to form a broad depressed plate, with the posterior angles produced, but not joining the ischia. A long and strong process is sent out from above the tuber ischii. Metapophyses are developed from the outside of the anterior zygapophyses, as far as these extend along the caudal series, viz. to the eighth vertebra; beyond these the metapophyses are developed, independently of the zygapophyses, to near the termination of the tail.

In the Long-tailed Armadillo (*Dasypus longicaudus*, Pr. MAX.), with *d* 11, *l* 5, the metapophyses commence, abruptly, as long slender obtuse processes, on the seventh dorsal (Plate XLIX. fig. 18, D 7, *m*) rising midway between the diapophyses (*d*) and prozygapophyses (*z*), and projecting obliquely upwards and forwards: they pass upon the outside of the base of the prozygapophyses of the eighth dorsal (D 8, *m*), develope an articular surface from the inner side of their base for an extension of the surface of the zygapophysis upon its outer side in the ninth and succeeding dorsals; in the eighth dorsal they also develope a second articular surface from the under part of their base for articulating with the anapophysis of the seventh dorsal. The metapophyses in the following vertebræ, retaining their two articular surfaces, progressively increase in length until they exceed the neural spines in this respect in the last three lumbar vertebræ. The anapophysis (a) commences on the seventh dorsal, projecting backwards behind the base of the diapophysis, and presenting on its upper side an articular surface for that beneath the base of the succeeding metapophysis. The anapophysis increases in length, but more so in vertical thickness in the succeeding vertebræ. The diapophysis (d) subsides to a mere ridge in the last dorsal and disappears in the lumbar vertebræ, where the transverse processes are formed by parapophyses. In the penultimate dorsal vertebra the anapophysis is notched posteriorly, and developes a small surface from below its inferior division for articulating with the head of the last rib. The succeeding anapophysis developes a similar surface for articulating with a short and thick exogenous process or 'parapophysis': and this complex condition of the anapophysis is continued throughout the lumbar region, the last vertebra having a longer and narrower anapophysis. Thus on each side of the fore-part of each lumbar vertebra there is *one* articular surface on the prozygapophysis, a *second* on the inner side of the base of the metapophysis, a *third* on the outer and under side of the same base, and a *fourth* on the upper side of the base of the parapophysis; and on each side of the back part of the same vertebræ there is *one* articular surface on the under side, and a *second* on the outer side of the posterior zygapophysis, a *third* surface on the upper, and a *fourth* on the under side of the anapophysis; making sixteen synovial joints, four on each side of both fore and back parts of the vertebræ, which joints may be called, beginning from above downwards, the 'zygapophysial,' 'metapophysial,' 'anapophysial' and 'parapophysial' articulations respectively*; and the power of inflecting the substantive names for the several processes and applying them adjectively to such modifications as I have described is not one of the least advantages of such substantive names to the descriptive Anatomist. These different articulations form double tenon-and-mortise joints on each side of the vertebræ. But their comparison with these joints in artificial carpentry, affords but a meagre idea of their true nature and complexity, whilst the supposition of their homology with the similar tenon-and-mortise joints of the backbone of Serpents is, as I shall presently demonstrate, unsupported by exact comparison.

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* I have ascertained that the vertebral column of the so-called 'Ant-eater' exhibited by Dr. MELVILLE at the meeting of the Zoological Society, on December 12, 1848, in order to demonstrate "that the Edentata had no posterior or backwardly projecting processes from the diapophyses," is not of a true Ant-eater, but of an *Orycteropus*, in which, although the development of the anapophyses is much less than in the species of *Myrmecophaga*, they are nevertheless sufficiently recognizable. In no order of Mammals, as I shall presently show, are the 'anapophyses' or 'backwardly projecting processes' more extraordinarily developed than in the *Edentata*.

In the *Dasypus tricinctus*, the true or moveable vertebræ present the following, amongst other, characters:—

The spine of the third cervical has completely coalesced with that of the dentata, which is thick and high, but more extended forwards than backwards. The spine of the fourth cervical is applied to its back part. The neural arches of the succeeding cervicals have no spines, but form thin transverse bars of bone above, which are incomplete in the middle at the fifth and sixth cervicals, upon which the rest are strongly bent backwards. Their bodies are extremely broad in proportion to their length or antero-posterior diameter. The articular bed for the head and tubercle of the first dorsal rib is contributed to in equal shares by the last cervical and first dorsal vertebræ. Ten vertebræ show the impressions of the articulation of the head of the rib in addition to the first dorsal, and the neurapophyses of these eleven vertebræ are directly perforated by the spinal nerves, Plate XLIX., fig. 19, *n*, *n**. The articulation for the last rib (*pl*) is as equally divided between the two contiguous vertebræ as is that of the first rib. The prominence (*p*) supporting the articular surface for the head of the rib answers to the parapophysis, just as the prominence for supporting the articulation for the tubercle of the rib, represents the diapophysis. The prominence in the first lumbar vertebra (*p*) which articulates with the under part of the anapophysis (*a*) of the last dorsal, repeats the prominence in that dorsal, which articulates with the head of the last rib; it is therefore a parapophysis. The diapophysis (*d*) projects, as in the dorsal vertebræ, from the upper and outer part of the base of the short and thick anapophysis (*a*), and this anapophysis presents, as in other Armadillos, two articular surfaces, one above, for the under part of the metapophysis (*m*), another below, for the upper part of the parapophysis (*p*). Thus the vertebræ are interlocked by tenon-and-mortise joints, as CUVIER has described, but it is by distinct parts of the vertebra from those which form the corresponding joints in the backbone of serpents.

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* The zygapophysial and metapophysial synovial sacs communicate and form a common joint in the posterior dorsal and lumbar vertebræ.

The metapophysis (*m*, 7) begins in the seventh dorsal as a distinct process: the anapophysis is first developed in the sixth (*a* 6), and articulates with the under part of the first metapophysis; the subsequent metapophyses (*m*, *m*) present the usual progressive and great development, as also the two joints, one on the inner and the other on the under side of their base. Nothing can be more distinct than the anterior and posterior zygapophyses of the sixth dorsal vertebra: but equally distinct are the metapophyses which coexist with them in the seventh dorsal; to confound these two processes, or to describe the longer metapophyses in the subsequent vertebræ as developments of the anterior zygapophyses, is to confound two things manifestly distinct.

In the *Dasypus sexcinctus*, some modifications of the accessory processes are present, which render a notice of its vertebral characters desirable.

The vertebral formula is seven cervical, eleven dorsal, three lumbar, nine sacral, sixteen caudal. The second and third cervicals have coalesced together, and they develope a strong confluent neural spine. The last four cervicals are without those spines, and are equally devoid of zygapophyses. The diapophysis of the last cervical contributes to the articular cavity for the tubercle of the first dorsal rib, which is enormously expanded; and the anchylosed pleurapophysis of the seventh cervical projects backwards beneath the head of the first dorsal rib. The neurapophyses of the middle dorsal vertebræ are directly perforated for the spinal nerves. Anapophyses are developed from behind the diapophyses of the first three dorsals; they decrease in size in the succeeding dorsals, but again increase in the posterior dorsals and in the lumbar vertebræ, where they present an articular surface to the metapophysis of the succeeding vertebræ. The metapophyses commence as ridges on the upper surface of the diapophyses of the second and third dorsals; they form prominent tubercles on the seventh and eighth dorsals, and rapidly elongate in the succeeding vertebræ, where they surpass in length and equal in thickness the neural spines. They are much diminished in length in the first sacral vertebra. Each of these elongated metapophyses presents a distinct articular surface to an accessory posterior zygapophysis; and on its opposite side an articular surface to the subjacent anapophyses of the preceding vertebra, producing two additional pairs of joints to the normal ones formed by the anterior and posterior zygapophyses.

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* This is one of so vast a series of exceptions to the "Loi de conjugaison" of Prof. SERRES, as to deprive it of any claim to be considered as the law of formation of foramina, and to demonstrate the abuse of the term 'law,' in cases like that in which it has been made to express the idea that every foramen is formed by the approximation of two notches in distinct bones.

The parapophyses of the lumbar vertebra do not materially increase in length, but chiefly in antero-posterior extent, overlapping each other, the back part of the anapophysis of the last dorsal resting on the fore-part of the parapophysis of the first lumbar vertebra, and the parapophyses of the last lumbar vertebræ similarly articulating with a prominence of the iliac bone; an additional pair of articulations being thus formed externally to those between the anapophyses and metapophyses.

The long sacrum has coalesced with both the iliac and ischial bones. The pubic bones complete a wide arch by their confluence at their slender symphysis. The ischiatic notches are converted into foramina, which are inferior in size to the foramina obturatoria. The spines of most of the sacral vertebræ form by their confluence a continuous ridge. The strong tuberosity of the ischium is bifid. The zygapophyses are developed and coarticulated in the first five caudal vertebræ. The anterior ones support short and thick metapophyses, and these are continued in the succeeding caudal vertebræ, after the anterior zygapophyses have disappeared.

In the Pangolin (*Manis pentadactyla*), with *d* 13, *l* 4, the metapophyses commence as tubercles on the first dorsal vertebra and rapidly increase in size. Anapophyses are not developed. The metapophyses continue to be developed from the sacral series. The transverse processes of the last sacral suddenly expand both in length and breadth, and articulate with the tuberosities of the ischium. Well-developed hæmal arches are articulated to the inferior interspaces of the caudal vertebra as far the penultimate one. The anterior zygapophyses cease upon the fourteenth vertebra of the tail, but the metapophyses are continued as far as the penultimate caudal.

In the Tamandua (*Myrmecophaga Tamandua*), with *d* 17, *l* 2, all the cervical vertebræ have spinous processes except the atlas; that of the dentata is produced forwards, not backwards, and those of the sixth and seventh cervicals are as long as the spine of the first dorsal, which exceeds in length that of any of the other vertebræ. The pleurapophysial part of the transverse process of the dentata is broad, and produced downwards and outwards: it increases in length and breadth in the four succeeding vertebræ, in the three last of which the diapophysial element of the process stands out distinctly and strongly. In the seventh cervical this element alone is developed, and the transverse process is accordingly said to be imperforate. A metapophysial tubercle is developed from the outer side of the prozygapophysis of the five last cervicals. The diapophyses of all the dorsals present an articular surface for the tubercle of the rib. The metapophysial tubercle is continued from the cervical to the dorsal region, appearing there upon the upper part of the diapophyses of the first dorsal; it continues increasing in size and length to the thirteenth dorsal, where it begins to shift its position, and in the remaining dorsals projects midway between the diapophysis and zygapophysis. In the fourteenth dorsal the metapophysis also increases suddenly in breadth, and developes an articular surface from its inner side to join an accessory posterior zygapophysis, as well as an articulation upon its fore and under part for the anapophysis of the preceding vertebra. In the fourteenth dorsal the anapophysis suddenly acquires increased length and breadth, with a distinct articular surface upon both its upper and under part, the upper one articulating with the metapophysis, the under one with the parapophysis of the succeeding vertebra. Thus there are not fewer than sixteen co-adapted articular surfaces, in addition to those for the head and tubercle of each rib and the articulations between the ends of the centrum of one and the same vertebra. In the first lumbar vertebra the diapophysis increases in thinness and decreases in length, presenting the form of a depressed plate; the other processes with thin articular surfaces are retained in both lumbar vertebræ. Parapophyses and metapophyses are also developed from the forepart of the first sacral vertebra, together with another accessory process extending to the parapophyses, projecting from the fore-part of the diapophyses, and presenting an articular surface to a corresponding accessory articulating process for the anapophysis of the last lumbar. The neural spines of the five sacral vertebræ have coalesced into a continuous ridge, on each side of the base of which are the tubercular representations of the metapophyses. The transverse processes of the last sacral are enormously expanded, and develope from their under part a broad rough prominence for syndosmosis with the anterior tuberosity of the ischium. The posterior and ordinary tuberosity of that bone projects freely outwards beneath the transverse processes of the first caudal. The metapophysial tubercles begin to be developed from above the prozygapophyses from the first to the eighteenth caudal, beyond which the metapophyses exclusively represent the articular processes. The broad transverse processes have an accessory tubercle near their extremities, as far as the sixth caudal; at the seventh they are notched at their extremities, and the notch deepens until it divides the diapophyses into two in the eighteenth vertebra, and so on till they disappear at the end of the tail. Hæmal arches are articulated between the vertebral interspaces of most of the caudals.

In the Great Ant-eater (*Myrmecophaga jubata*), with *d* 15, *l* 3, the transverse processes of the atlas are pierced in two places obliquely at the fore-part of the neural arch on each side. The axis has a transverse perforation on each side the neural arch anterior to the transverse process, which is imperforate. The transverse processes of the three succeeding cervicals are imperforate, the vertebral artery entering the neural canal behind and perforating obliquely the base of the neurapophysis anteriorly, as in the *Camelidæ*. In the sixth cervical, the canal for the vertebral artery runs through the base of the transverse process. These processes are much extended antero-posteriorly in all the cervicals and overlap each other. The diapophysial and pleurapophysial portions are very distinct in the fifth and sixth cervicals. The spines of the third and sixth cervicals inclusive are triangular and pointed; that of the seventh is longer than the rest and truncate above; it is much exceeded in antero-posterior diameter by the spine of the first dorsal, but not in height. A metapophysial tubercle is developed from the outer side of the anterior zygapophysis in all the five posterior cervicals. It is placed more outwardly in the first and second dorsals, and gets upon the top of the diapophyses in the succeeding dorsals. In the eleventh dorsal the metapophysis (Plate XLIX. fig. 20, *m*) begins to resume its former position, and developes an articular surface (Plate L. fig. 21, *front*, *m a*) from its under part, which joins the upper articulating surface (Ib. *back*, *a m*) of the anapophysis (*a*) of the preceding vertebra. In the thirteenth dorsal, the metapophysis (*m*) is half-way between the diapophysis and anterior zygapophysis, and repeats the same articulation with the anapophysis. In the last two dorsal vertebræ, the base of the metapophysis developes a second articular surface (Plate L. fig. 22, *front*, *m z*) from its inner side, which joins a new or accessory articular surface (ib. *back*, z') on the outside of the posterior zygapophysis of the antecedent vertebra. This tenon-and-mortise articulation of the metapophysis with the zygapophysis on the inner side and with the anapophysis on the outer side, is repeated throughout the whole lumbar series. The anapophysis (*a*) begins to be developed from the anterior dorsal vertebra, and even there presents an articular surface (Plate L. fig. 21, *back*, *a p*) at its under part to join a corresponding surface (ib. *front*, *p a*) on a parapophysis (*p*) developed from the fore and outer part of the neural arch of the succeeding vertebra. In the tenth dorsal a second articular surface (ib. *back*, *a m*) is established in the upper part of the anapophyses for the inferior metapophysial one (*m a*) of the succeeding vertebra; here, therefore, the anapophysis begins to be mortised between the parapophysial and metapophysial articular surfaces, which surfaces continue to the antepenultimate lumbar vertebra, from which, forwards, to the eleventh dorsal, there are sixteen joints between each pair of vertebræ, as in the Armadillo. But this complication goes further in the Great Ant-eater, for, in the penultimate lumbar vertebra, a third articular surface (Plate L. fig. 23, *back*, *a d*) is developed from the under and outer part of the anapophysis (*a*), which joins an articular surface (fig. 23, *front*, *d a*) on the upper and fore-part of the diapophysis of the last lumbar; and this vertebra is united in a similarly complex manner with the first sacral vertebra, which would make eighteen synovial joints, in addition to those at the ends of the centrum, but that those between the normal articular processes, or zygapophyses, are suppressed. The true serial homology of the processes (*p. p.*) as 'parapophyses,' developed from the fore-part of the base of the neural arch to articulate with the under part of the anapophyses, is well illustrated by the vertebræ of the Great Ant-eater, and, as will be afterwards shown, in the Megatherium, in which the true diapophyses are better developed than in the Armadillos.

Definite terms for those several processes that undergo such remarkable modifications in the great *Edentata* become indispensable; they could scarcely be rendered intelligible by the ordinary descriptive periphrases. But, by means of single substantive names, all their modifications can be defined, and, by adjectival inflections of those names, the articular surfaces can be distinguished.

In figures 21, 22 and 23, Plate L., initial letters indicate the processes on one side, and the articular surfaces on the other side of each vertebra, thus:—

m is the metapophysis, with *m a* its 'anapophysial,' and *m z* its 'zygapophysial' articulations.

d is the diapophysis, with *d pl* its 'pleurapophysial,' and *d a* its 'anapophysial' articulations.

p is the parapophysis, with *p a* its 'anapophysial' articulation.

a is the anapophysis, with *a m* its 'metapophysial,' *a p* its 'parapophysial,' and *a d* its 'diapophysial' articulations.

z and *z'*, in figs. 21 and 22, indicate the ordinary anterior and posterior zygapophyses; they become very small in the middle dorsal vertebræ, and are suppressed in the posterior dorsals and lumbars: the process *z'* in figs. 22 and 23 is not a gradual modification of the posterior zygapophyses, *z'* in fig. 21, but is a substitution for them, called out, as it were, by the new surface *m z* upon the metapophysis.

As the complex structure of the vertebræ of the Armadillos and Ant-eaters has, hitherto, been sought to be illustrated by reference to the vertebræ of Serpents, it becomes necessary, after the foregoing analysis, to ascertain how far the analogy holds good.

The Ophidian reptiles so far resemble the *Mammalia* in their vertebral characters, that all the autogenous elements, except the pleurapophyses (Plate LI., fig. 31, 32, *pl*), coalesce with one another in the trunk, and the pleurapophyses (*ib.*, fig. 28, *pl*) themselves become anchylosed to the diapophyses (*ib. d*) in the tail. But the exogenous processes present many differences from those in *Mammalia*. The diapophysis (figs. 24 and 25, *d*) extends from the fore-part of the side of the centrum, and is large, vertically oblong or hemispherical (fig. 38, *d*), and very short: it is covered by the articulation for the head of the rib*. The base of the neural arch swells outward from its confluence with the centrum, and developes from each angle a transversely elongated zygapophysis; that (z) from the anterior angle looking upwards, that (z') from the posterior angle looking downwards, both surfaces being flat and almost horizontal. A wedge-shaped process, which I have termed 'zygosphene[*]' (fig. 25, $z\,s$), is developed from the fore-part of the base of the spine; the apex of the wedge being truncate or emarginate, and the converging sides presenting two smooth, flat, articular surfaces. This wedge is received into a cavity, which I have called 'zygantrum[†]' (fig. 26, $z\,a$), excavated in the posterior expansion of the neural arch, and having two smooth articular surfaces to which the zygosphenal surfaces are adapted. Thus the vertebræ of Serpents articulate with each other by eight joints, in addition to those of the cup and ball on the centrum; and interlock by parts reciprocally receiving and penetrating one another. This is the most conspicuous, but is not, as has been affirmed[‡], the peculiar characteristic of the Ophidian vertebra; the zygosphenal ($z\,s$) and the zygantral ($z\,a$) surfaces being developed in certain Lizards, as *e.g.* the Iguana (Plate LI., figs. 40–42, $z\,a$, $z\,s$); where the zygosphene ($z\,s$, fig. 41) is deeply notched anteriorly, and the zygantra ($z\,a$, fig. 42) are shallow and separated from each other behind.

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* This may be the 'head' of the rib in the same sense in which it would be said of that end of the simple rib which articulates with the diapophysis in the hinder dorsal vertebræ of the Crocodile. Guided by this modification of the ribs in that reptile, the Anatomist would be led to the homology of the simple ribs, and of the

In the vertebræ of Reptiles and Mammals with double 'tenon-and-mortise' joints, the only articulating processes which are truly homologous are the zygapophyses (z, z' in all the figures): the superadded processes in the Reptiles are, the zygosphene ($z\,s$) and zygantra ($z\,a$). A median 'tenon' and two lateral 'mortises' at the fore-part of the vertebra, and a median 'mortise' and two lateral 'tenons' at the back part of the vertebra, all of them *above* the true zygapophyses, are the result of the superaddition in Serpents; whilst in the Edentates a median mortise and two lateral tenons in front, and a median tenon and two lateral mortises behind the vertebra, are all of them *below* the true zygapophyses, and are the result of the additional processes called 'metapophyses' and 'anapophyses;' whilst a second pair of 'tenons

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sustaining transverse processes in the Lacertians and Ophidians, which is indicated by the term 'diapophysis' applied to those processes. If, however, the lower articulating process in the bifurcated anterior ribs of the Crocodile be not regarded as the superadded part, but as answering to the head of the simple rib in the Snake, then the transverse process to which this is attached will be a 'parapophysis,' and the position of such transverse process in certain parts of the vertebral column, would lead to that supposition. But the modifications of the processes in question, in the Ophidian series, would indicate them to include, as in the *Batrachia* and in the neck of the *Plesiosaurus*, both diapophysis and parapophysis: and it is in this extended sense that I apply, for the sake of convenience, the term 'diapophysis' to the entire process in Ophidia and Sauria.

[*] *Ζυγὸν, a yoke, σφὴν, a wedge.*

[†] *Ζυγὸν*, and *ἄντρον, a cavity.*

[‡] Cuvier, Leçons d'Anat. Comp. Ed. 1835, t. i. p. 216; where, after the double articular processes are described, it is stated, "Ces apophyses sont agencées de manière qu'il resulte, comme pour les vertèbres lombaires de certains Edentés, que deux vertèbres sont articulées entre elles par un double tenon entrant dans une double mortaise. La seule différence, c'est que les facettes de tenon et de la mortaise supérieurs sont continues et forment entre elles un angle aigu." The complex joints are, however, formed by different processes in the *Reptilia* and *Edentata*, as is explained in the text.

and mortises' is superadded below the others, in some Edentates, by the special development of the anapophyses and of parapophyses.

I know not how these complex but constant characteristics differentiating the Ophidian and Mammalian vertebræ could be intelligibly made known without the use of 'names' for the parts; and, as I trust, that I have shown the parts to be not mere subdivisions of the diapophyses, but constant, characteristic, and independent processes, definite names for them cannot be reasonably deprecated as unnecessary*.

Before leaving this part of my subject, I may point out a few of the modifications of the exogenous processes of the vertebræ, by which different genera of *Ophidia* may be distinguished.

In the genus *Coluber* (Plate LI., fig. 29–32), the diapophysis, besides developing the articular tubercle (*d*) for the rib, sends a long process (*d''*) outwards above that tubercle, between it and the prozygapophysis (*z*), and a very short process (*d'*), like a parapophysis, downwards below that tubercle: the neural spine (*n s*) is low in proportion to its antero-posterior extent: the zygosphenal surfaces (*z s*) are nearly vertical, and the zygantra (*z a*) are wide apart: the hypapophysis (fig. 32, *hy*) beyond the anterior fourth part of the vertebral column is reduced to a straight ridge, and is not produced posteriorly.

In the Sea-Serpent (*Hydrus*) (fig. 33.), the diapophysis also sends out a process above and below the articular tubercle; but that which seems to underprop the zygapophysis, does not extend so far out as in the *Coluber*. The neural spine (fig. 33, *n s*) is higher in proportion to its antero-posterior extent: a very small hypapophysis projects below the articular ball of the centrum, and a low ridge is continued from it along the under part of the centrum.

In the *Naja* or Cobra di Capello, the neural (fig. 34, *n s*) spine is lower, but the hypapophysis (*hy*) is longer than in either of the preceding genera. The diapophysis presents a well-marked articular tubercle (fig. 35, *d*) upon its upper part, and both the upper (*d''*) and lower (*d'*) processes are well-marked, although the former is shorter than in the genus *Coluber*.

The Rattle-Snake (*Crotalus*) (fig. 36–39) is remarkable for the development of the hypapophysis (*h*) to an equal length with the neural spine (*n s*) throughout the vertebræ of the trunk; such development being restricted to the anterior vertebræ in most other genera: and any single vertebra might be distinguished from an anterior trunk-vertebra of a Boa or Python, for example, by the following characters:—The diapophysis developes a small hemispheric tubercle (*d*) from its upper convexity; and a process (*d'*) from its under part extending downwards and forwards below the level of the centrum (*c*); the anterior zygapophysis (*z*) seems to be supported by a similar process (d'') from the upper end of the diapophysis, the point of which projects a little beyond the end of the zygapophysis (*z*, fig. 37): I refrain from giving names to these upper and lower processes, because they really are nothing more than mere subdivisions of the diapophyses, and characterize the vertebræ of a few genera of a single order of Reptiles.

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* See the criticism in 'Proceedings of the Zoological Society,' December 12, 1808, in which the author,—"Understanding that Professor Owen had proposed names for these mere subdivisions of the diapophyses, strongly deprecated the overloading this difficult part of anatomy with unnecessary names," p. 146; and yet he proceeds "to animadvert upon Cuvier and M. de Blainville for having neglected to describe them," as if they could be intelligibly described without determinations and names. What is truly to be deprecated is the unnecessary change of names when once rightly applied.

In the Boas and Pythons (fig. 24–27) the divisions (d'' and d') of the diapophysis are wholly wanting; that process is entirely occupied by the articular surface for the rib, which is vertically oblong, convex in the axis of the centrum, and convex vertically at its upper half, but concave vertically at its lower half. The base of the neural arch swells outward, from its confluence with the centrum, and developes from each angle a zygapophysis, which is much longer transversely than in any of the preceding genera of Serpents (fig. 27, *z*, z'). The zygosphene (fig. 25, *z s*) is narrower in proportion to its height, and the zygantrum (fig. 26, *z a*) is correspondingly deeper and more circumscribed. In an African Constrictor (*Python regius*), which measured 15 feet 6 inches in length, and had 348 vertebræ, the first seventy had long hypapophyses, which afterwards subsided into the obtuse ridge and tubercle shown at fig. 27, *hy*.

Of the value of the minute and apparently insignificant modifications of the vertebral processes above described, some idea may be formed by their application to determine the nature and affinities of the great Serpent, of which the vertebræ have been found fossil in the eocene tertiary deposits of Kent and Sussex. The veritable Ophidian nature of the fossils in question is demonstrated, not only by the superadded zygosphenal (*z s*, fig. 45) and zygantral (*z a*, fig. 46) articulations, but by the solidity of the zygosphene, by the size and form of the centrum, by those of its articular cup (*c*, fig. 45) and ball (c', fig. 46), and of its hypapophysis (*hy*); and also by the size and prominence of the diapophysis (*d*). The largest vertebræ, probably from about the middle of the body, as compared with the vertebræ from the same part of the skeleton of a *Python Sebæ*, 20 feet in length, are longer in proportion to their breadth, and the cup and ball of the centrum are larger; the hypapophysis (*h*) is more produced, and there is a second smaller hypapophysis close to the anterior part of the under surface of the centrum, which in most of the large vertebræ is connected by a ridge with the hinder and normal hypapophysis (fig. 47, *hy*), but in a few vertebræ is not so connected. The articular cup and ball are less obliquely placed upon the extremities of the centrum, being nearly vertical. The rim of the cup is sharply defined, and is more produced from between the bases of the diapophyses; a deeper and narrower chink intervening than in the Python. The transverse diameter of the cup (*c*, fig. 45) is greater than that of the zygosphene (*ib.*, *z s*),—a proportion which I have not found in the vertebræ of any existing genus of Serpent, in which the base of the zygosphene always equals at least the parallel diameter of the articular cup. The articular part of the diapophysis (*d*) is more produced outwards, and less extended vertically in *Palæophis* than in *Python*, and it is uniformly convex; a ridge is continued from its upper end obliquely forwards; as far as, but not beyond, the apex of the anterior zygapophysis (*z*), forming the angle between the lateral and anterior surfaces, whilst the horizontal articular facet forms the third surface of that three-sided conical process. In the *Python* the non-articular part of the same zygapophysis is convex, and the process is much more extended outwardly; the proportions of the zygapophysis in the *Palæophis* more resemble those in the *Coluber* and *Hydrus*, but differ from these, as also from *Naja* and *Crotalus*, in the non-extension of the diapophysial point beyond the articular surface.

A ridge or horizontal rising of the bone extends from the anterior to the posterior zygapophysis, but is more or less blunted or subsides midway, and is by no means so produced outwards as in Python; in this respect more resembling that in *Coluber* and *Hydrus*. Below the middle of this ridge, on a level with the upper surface of the centrum, there is a short, nearly parallel rising in *Palæophis* (fig. 44). The zygosphene (fig. 45, *z s*) is slightly excavated anteriorly, and shows no trace of the tubercle which characterizes the middle of that surface in the *Python* (fig. 25); it is also broader in proportion to its height. But perhaps the most characteristic feature of the vertebræ of the *Palæophis*, is the peculiar production of the posterior border of the neurapophysis into an angle (*n*, fig. 44) directed upwards, outwards, and backwards: there is no trace of this process in the *Hydrus* (fig. 33), or the other existing genera of Serpents. The posterior zygapophysis resembles, of course, the anterior one in its much less extent, especially transversely, as compared with that in the *Python*; and the posterior border of the neurapophysis (fig. 44, *z′*, *n*) rises from its apex vertically, or a little inclined outwards and backwards, giving a squarish form to the surface of the neural arch in which the zygantra (*z a*, fig. 46) are excavated; these cavities, in proportion to the articular ball beneath, are smaller and less deep than in the *Python*, or any other existing genus of Serpent. The sloping sides of the neural arch above the zygapophysial ridge are more concave than in *Python*, and so resemble those parts in *Coluber* and *Hydrus*. The latter genus (fig. 33) and *Crotalus* (fig. 36) most resemble *Palæophis* in the proportions of the neural spine (*n s*); this part, however, in *Palæophis* differs from that of *Hydrus* in having its base coextensive with the supporting arch, springing up from the forepart of the zygosphene, whilst the zygosphene entirely projects forwards, clear of the base of the spine in *Hydrus*, as in *Python*, *Coluber*, and *Naja*; but in *Crotalus* the base of the spine has the same antero-posterior extent as in *Palæophis*. The neural spine had been more or less fractured in every detached specimen of the brittle crumbling vertebræ of the *Palæophis Typhæus* from the Bracklesham Clay;—only one specimen, which I carefully worked out in relief, from a mass of matrix, after imparting some of its original tenacity to the substance of the bone, afforded a true idea of the peculiar character of these Ophidian vertebræ, which is afforded by the great height of the neural spine, as shown in figure 44.

Of the Hypapophysis.—Some idea of the nature and importance of this process may be formed by its constancy and range of variation in the Ophidian Reptiles, and especially by its degree of development in the genus *Crotalus* (Plate II., fig. 36–39, *hy*), which is maintained throughout the vertebræ of the trunk. It is present, under various modifications, in certain regions of the vertebral column, in most other reptiles; as likewise in Birds, and in a certain proportion of the mammalian class.

Coiter seems first to have noticed this process in the Hare, and subsequent comparative anatomists have pointed out this peculiarity of certain lumbar vertebræ of the *Leporidæ*, as 'an inferior spinous process.' It is not, however, the inferior 'homotype,' or answerable part on the lower or ventral aspect of the vertebra, to the 'spinous process' above; this is properly repeated by a true inferior or hæmal spine developed from the apex of the arch on the ventral aspect (Plate LIII., fig. 60, *h, h s*), which arch answers to the neural arch (*ib. n, n s*) on the dorsal aspect of the vertebra. The hypapophysis is a process commonly exogenous and always developed from the body of the vertebra, not from the hæmal arch. Cuvier applies the same term 'épine inférieure' to the exogenous processes from the centrum of the vertebræ of the Rattlesnake and Hare, and to the autogenous hæmal spines in Fishes.

In the Hare (*Lepus timidus*) the hypapophysis appears as a ridge in the posterior dorsal vertebræ, is developed into a process in the last dorsal, rapidly increases in length in the first and second lumbar vertebræ, inclines forwards in the third, and is suddenly reduced again to a mere ridge in the fourth and following lumbars.

In the Rabbit (*Lepus caniculus*) it is a low ridge in the posterior dorsals: the ridge is produced into a low angle in the first lumbar; becomes a longer and more slender process in the second lumbar; inclines forwards at a more acute angle in the third lumbar than in the Hare; and subsides to a mere ridge in the succeeding lumbars. There is a short hypapophysis from the middle of the inferior part of the ring of the atlas, in both the Hare and Rabbit; and in most other Rodents. In the Guinea-pig (*Cavia porcellus*) a hypapophysis is developed from beneath both atlas and dentata.

The hypapophysial ridge is strongly marked upon the lumbar vertebræ in the genus *Dasyprocta*: but the most constant location of the inferior exogenous processes from the centrum is in the caudal region, where they are frequently associated with a hæmal arch and spine.

In the Cape Hare or Jerboa (*Helamys capensis*) the hypapophysis, in the middle caudal vertebræ, arises from the fore-part of the under surface of the centrum, and immediately bifurcates: in some of the vertebræ anterior to these, a hæmal arch is attached to the ends of the bifurcate hypapophysis: towards the end of the tail the hypapophysis appears as two short diverging processes.

The modification which consists in a single process becoming double, affects most of the exogenous processes in certain parts of the vertebral column in the vertebrate series. We have already seen that the metapophysis is double in the anterior thoracic vertebræ of the Ornithorhynchus: the diapophysis, which is single in the trunk, not unfrequently becomes double in the tail; and the hypapophysis commonly undergoes the same modification in that region.

In the Australian Water-rat (*Hydromys chrysogaster*) there are two pairs of hypapophyses in the fifth to the tenth caudal vertebræ inclusive, in most of which the anterior pair, homologous with that in *Helamys*, are longer than the posterior pair. But in such an exceptional instance it is not necessary to multiply names for the superadded or rather subdivided processes; the purposes of correct and definite description being sufficiently answered, by distinguishing under the name '*hypapophysis*' those, commonly exogenous, inferior processes of the centrum, whether single or in pairs, from the autogenous hæmal arches and spines, with which they have usually been confounded.

In the anterior thoracic and the cervical region of Crocodiles and Lizards the hypapophysis is constant and commonly single, but I have met with fossil vertebræ of a Crocodile in which the cervical hypapophysis was divided in the median plane, so as to form a pair*. The basioccipital sends down a pair of hypapophyses in the *Iguana* and *Mosasaurus*†, as likewise in Ruminants. This bifid modification is more commonly found in the caudal vertebræ of Reptiles, as it is in Mammals; but in the *Iguanodon* some of the caudal vertebræ have the hypapophysis single, where, *e.g.* it supports the coalesced bases of the hæmapophyses of such vertebræ.

In the Saw-toothed Seal (*Leptonyx serridens*) the cervical and anterior dorsal vertebræ have a hypapophysial ridge, which, in the latter, is produced into a tuberosity: the lumbar vertebræ are characterized by a pair of hypapophyses from near the hinder end of the centrum.

In the *Phoca grœnlandica* the strong hypapophysial ridge of the lumbar vertebræ also divides into two tuberous processes. These processes indicate the great development of the anterior vertebral muscles, *e.g.* the 'longi colli' and 'psoæ'; and relate to the important share which the vertebræ and muscles of the trunk take in the locomotion of the Seal-tribe, especially when on dry land, where they may be truly called 'gasteropods,' in respect of their peculiar mode of progression.

The hypapophysis is pretty constantly developed in the cervical region of the Ungulate quadrupeds, especially in the artiodactyle division. It is single in the atlas of the Hippopotamus, but divides into two ridges, diverging as they extend backwards, and terminating in tuberosities in the second and third cervical vertebræ: in the fourth they begin to subside, and disappear in the fifth cervical vertebra. A pair of hypapophysial tubercles reappear in the third lumbar vertebra of the Hippopotamus.

In the great extinct Irish Deer (*Megaceros Hibernicus*) the hypapophysis is a strong single ridge developed into a tuberosity in most of the cervical vertebræ. The atlas has a hypapophysis in most Ruminants.

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* On Fossil Reptiles from New Jersey, Quarterly Journal of the Geological Society, November 1849, p. 380, pl. 10. fig. 2.

† *Ib.* pl. 10. fig. 5.

In the Musk-deer the dentata has a sharp hypapophysial ridge, extending from below the base of the odontoid to beyond its posterior surface, where it underlaps the next vertebra. A similar ridge, ending in a backwardly produced process, is developed from the two succeeding cervicals; beyond which the hypapophysis gradually subsides to the seventh cervical.

In the Camel (*Camelus bactrianus*) the atlas has no hypapophysis; but this commences as a ridge from the hinder half of the centrum of the dentata, expands as it proceeds backwards, and divides into two tubercles. In the third and fourth cervicals it is principally represented by the pair of posterior tubercles, which subside in the fifth cervical vertebra.

The dentata of the Giraffe has a strong hypapophysial ridge from near the forepart of its body.

In the Monotremes the atlas is remarkable for a modification of the hypapophysis, similar to that which it undergoes in the caudal vertebræ of most Mammals; it forms, *e. g.* a pair of processes which diverge from one another: in the succeeding cervicals the hypapophysis is single.

As the aim of the present communication is to demonstrate the individuality and distinctness of the exogenous processes, and their title to distinct names, the modifications of each in any given class will not be traced further than appears requisite to attain the proposed end: and I shall conclude the present notice of the exogenous processes in the Mammalian class, by applying the principles and nomenclature above defined to the description of some caudal vertebræ.

Plate LIII., fig. 60, is the first caudal vertebra of the *Myrmecophaga jubata*, in which the hæmapophyses *h h* are superadded and articulated to the hypapophyses *hy hy*, forming a hæmal arch: in the succeeding vertebræ the hæmapophyses coalesce at their lower ends, and develope a true inferior or hæmal spine. *n*, *n*, are the neurapophyses; *n s*, the neural spine; *z*, the zygapophyses, here coexisting with *m* the metapophyses. The transverse process is long and single on each side, and consists of an exogenous base or 'diapophysis,' *d*, and an anchylosed 'pleurapophysis,' *pl.*

Fig. 61, A, is an upper view of the seventh caudal vertebra of a Beaver (*Castor fiber*), where *n n* are the neurapophyses, which have ceased to coalesce with each other and complete the neural arch: *m m* are the metapophyses; *d d* are the anterior diapophyses, and *d′ d′* the posterior diapophyses. Fig. 61, B, gives an under view of *d d* and *d′ d′*, and of the hypapophyses, *h h.* Fig. 61, C, is the front view of the same vertebra, showing *n*, *m m*, *d d*, and *hy.*

Fig. 62, A, B, C, is the ninth caudal vertebra of the Kangaroo; *n′ n′* are the neurapophyses, which, coalescing at *n*, form the neural arch, now reduced to its smallest dimensions: *m*, *m* are the metapophyses; all trace of zygapophyses or articular processes has now disappeared from both the neur- and met-apophyses: *d d* are the anterior, and *d′ d′* the posterior diapophyses. These are, also, shown in the view of the under surface of the same vertebra, fig. 62, B, in which the hypapophyses *hy*, *hy* are figured. Fig 62, C, gives an anterior view of the centrum with *m m* the metapophyses, *d d* the anterior diapophyses, and *hy* the hypapophyses, diverging from it, as exogenous processes. The neurapophyses *n n* and the posterior diapophyses *d′ d′* are also seen.

Many excellent figures of the caudal vertebræ of different species of Mammalia are given in the 'Ostéographie' of M. DE BLAINVILLE, the characters of which may be readily understood by the above definition of the processes that diverge from them.

In the class *Aves*, the hypapophyses attain their maximum of development and range of variation in the Penguins (*Aptenodytes patachonica*, Plate LII., fig. 48). Single and long on the first four vertebræ of the neck, especially on the dentata, their place is taken by a pair of short processes in the sixth cervical, which processes increase in size in the four following vertebræ, converging in the last (*h h*, C_{10}) so as almost to complete a bony canal for the carotids: in the eleventh cervical (C_{11}) they have coalesced again into a single median plate, with its extremity extended both forwards and backwards; this plate decreases in the three following vertebræ. In the next, which may be regarded as the first dorsal, the hypapophysis again appears as a pair of processes (D_1, *h h*); both of these are broad plates, almost coextensive with the under surface of the vertebra and diverging from each other (fig. 49, *hy*). The common base of the diverging plates progressively lengthens in the second (fig. 50) and third dorsals, and the hypapophysis appears in the succeeding ones as a strong vertical plate, simply expanded at its end, and growing somewhat shorter to the last (fig. 51, D_4, *hy*).

In the *Sphæniscus minor*, the first dorsal vertebra, or the fourteenth vertebra from the head, presents three hypapophyses, which appear to be blended together in the next vertebra so as to form the common base of a pair of diverging plates. The hypapophyses in the Penguins have an analogous function to that in the Seals, extending the surface of attachment of the powerful muscles on the ventral aspect of the vertebral column, which so materially aid in the shuffling gasteropodal movements of both kinds of aquatic animals, when on land.

The hypapophysis is well-marked in the anterior cervical vertebræ, especially the dentata, in most birds: it usually reappears, as a pair of processes, from the parapophyses of the lower cervicals; which hypapophyses converge as they approach the dorsal region, and coalesce into a single process in the anterior vertebræ of this region, and in some birds in the lower cervicals.

In the Pelican, the parial hypapophyses coalesce at their lower extremities, and form a hæmal arch for the carotids in many of the lower cervicals.

The anterior trunk-vertebræ in many Siluroids are anchylosed by a hypapophysial development of bone continued from beneath one vertebra to another, and which is sometimes perforated lengthwise by a canal lodging the aorta*. The neck of the

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* On the Archetype of the Vertebrate Skeleton, p. 92.

Ichthyosaurus derives additional strength and fixation from hypapophyses autogenously developed, at the inferior interspace between the occiput and atlas, and at those between two or three succeeding cervical vertebræ*. The so-called 'body of the atlas,' in recent Saurians, Birds, Mammals and Man, is the homologue of the first of these subvertebral wedge-bones, and represents only the hypapophysial or lower cortical part of such body. The odontoid process of the second vertebra is the central and chief part of the body of the atlas†, but not the whole body, as Cuvier describes in the fimbriated Tortoise‡.

The most interesting and instructive steps in the transition of this main part of the centrum of the atlas to the modified condition which it presents in Man, and which is signified by the term 'processus odontoïdes' in Human Anatomy, are exemplified in the order *Chelonia*. In the Australian Long-necked Tortoise (*Hydraspis longicollis*, Bell), I find the centrum (*c c*, figs. 57, 58, Plate LII.) completely anchylosed with the neural arch (*n*) of the atlas, with the exception of the hypapophysis (*hy*), which is autogenous in this vertebra and preserves its distinctness. In the Soft-turtles (*Trionyx*) (*ib.* figs. 52, 53 and 54) both the centrum and hypapophysis of the atlas maintain their primitive individuality: the centrum (*c*) is relatively shorter than in the *Chelys* and *Hydraspis*; it presents a subcubical form; has a small subcircular surface (*c*, fig. 55) on its lower and fore-part for articulating with the hypapophysis; above this it expands transversely and presents a convex articular surface adapted laterally to the bases of the neurapophyses, and, mesially, completing the cup for the occipital condyle, and filling up the vacancy shown at *c*, fig. 53: the back-part presents a concave surface (*c*, fig. 56) which articulates with the anterior convexity of the centrum of the dentata. The neurapophyses of the atlas (fig. 54, *n*) rest partly upon their proper centrum (*c*), partly upon its hypapophysis (*hy*): their bases nearly meet above the centrum, and their apices quite meet, uniting by suture above the neural canal (fig. 53). The degradation of the centrum of the atlas to the odontoid process of the axis is completed by its confluence with the centrum of the latter vertebra, and by the total transference of the neurapophyses of the atlas to the hypapophysis. Fishes, Batrachians and the extinct Enaliosaurians, manifest the typical state of the atlas, the Warm-blooded Vertebrates its aberrant state, the transitional modifications are traceable in the Chelonian, Lacertilian and Ophidian reptiles§.

When the hypapophysis attains so complex a form as to be perforated and thus to constitute an arch protecting a vascular canal, it may readily be mistaken for something more than the mere *analogue* of the 'hæmal arch' of the typical vertebra; and, in my earlier investigations on that subject, I was led into the error|| of regarding it

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* Sir Philip de Malpas Grey Egerton, Bart., F.R.S., in Geol. Trans. 2nd Ser. vol. v. p. 187, pl. 14.

† Annals of Nat. History, vol. xx. 1847, p. 92.

‡ Ossemens Fossiles, tom. v. pt. ii. p. 207.

§ See the description and figures of the atlas and axis of the Python in my 'History of British Fossil Reptiles,' Part III. p. 136, pl. 3 (*Ophidia*), figs. 38—40.

|| Geol. Transactions, vol. v. 2nd Ser. p. 519, pl. 44, figs. 2 and 3.

as the *homologue* of that arch. The perforated hæmal arch in the cervical vertebræ of the Pelican, and the parallel descending processes similarly protecting the caudal artery in the Python (Plate LI., fig. 28), are alike exogenous growths from the centrum, and are serially homologous with the hypapophysis, not with the hæmapophysis. The total absence of true ossified hæmapophyses throughout the trunk and tail vertebræ, is a striking characteristic of the Ophidian reptiles*, as it is of fishes.

The determination of the homology of the autogenous hæmal arches in the tail carries with it that of the question of their relation to the inferior and sometimes perforated exogenous processes of the centrum in more advanced parts of the vertebral column.

The vast difference in point of size between the so-called 'chevron-bone' of the Crocodile and the bony arch formed by the sternal and vertebral ribs of a thoracic vertebra, seems at first sight to discountenance the idea of any homology between them. But the difference is not greater than that between the neural arch of the parietal segment of the skull in Man, and the arch formed above the middle dorsal vertebra: yet I think it may be now assumed as a settled point in anatomy, that those arches are homotypes or serial homologues. The difference in point of size is, indeed, much less in the cold-blooded and small-brained Vertebrates than in Man; but the transition from the abdominal to the caudal hæmal arches in fishes is much more gradual than that of the cranial to the abdominal neural arches in the same class, whilst the similarity of the neural and hæmal arches to one another is so close throughout the region of the tail, as to impress the mind with a conviction that they are alike the result of modified annular elements, in short, 'vertical homotypes.' CUVIER, accordingly, designates them by the same descriptive phrases†.

The general proposition that the 'chevron bones' or 'inferior annular part and spine' of the vertebræ in the tail of fishes, are modifications of the hæmal arches in the trunk, may be deemed to be unassailable. But the hæmal arch is a complex whole, and may include diapophyses or parapophyses with pleurapophyses, hæmapophyses and hæmal spine. In the abdomen of fishes the bony arch is incomplete below, and in its most complex state consists only of parapophyses and pleurapophyses. With the exception of the clavicular and pubic arches, bony hæmapophyses are developed in no part of the trunk of fishes. When, therefore, we rigidly scrutinize the composition of the hæmal arches in the tail, we find them composed of parts quite distinct from true hæmapophyses, and also composed of different vertebral elements in different species of fishes, a fact which adds to the proof of the essential serial homology of those arches in the tail with the hæmal arches in the trunk. In many osseous fishes the hæmal arches in the tail are formed by the gradual bending down and coalescence of the parapophyses: in some the union

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* Cartilaginous appendages to the pleurapophyses in Serpents may be viewed as rudimental 'hæmapophyses.'

† "Les caudales ont une partie annulaire et une apophyse épineuse en dessus et en dessous." CUVIER, 'Leçons d'Anat. Comp.' Ed. 1835, t. i. p. 223.

is effected by a transverse bony bar prior to the actual confluence of those processes, and pleurapophyses continue to be attached to some of the parapophyses after their transmutation into the hæmal arches, as *e.g.* in the Tunny, the Dory and the Salmon*. Nevertheless, in the Salamandroid *Polypterus* and *Lepidosteus*†, and in the nearly allied *Protopterus* and *Lepidosiren*, the true pleurapophyses gradually bend down and unite to form the hæmal arches in the tail; whilst in the *Amia calva* the pleurapophyses coalesce to form the inferior spine, continued from the hæmal arch, formed by the coalesced parapophyses‡. In the Cod-tribe (*Gadidæ*) the progressively reduced pleurapophyses coalesce with the parapophyses to form the hæmal arches. In Ophidians, as in Fishes, the transition from the trunk to the tail is not interrupted by the modification of any of the vertebral segments to form a 'pelvis.' The ribs are supported by diapophyses, with which they become confluent in the tail, where some of the pleurapophyses are singularly modified, bifurcate or thickened at the extremity, but never bent down and united together to form the hæmal arch: as there are no bony hæmapophyses completing the hæmal arch in the trunk, the succeeding segments of the tail retain, or have been influenced by, the same modification of vertebral development, and the analogue of the hæmal arch is formed, as I have before observed, by a pair of parallel exogenous hypapophyses (Plate LII., fig. 28, *hy*), and is open below, like the incomplete hæmal arches throughout the trunk. In Lizards and Crocodiles a new vertebral element appears to be introduced to complete the hæmal arch in the chest; it is, however, only a repetition of an element which, under a more developed and modified form, completes the hæmal arches in the head, in both fishes and reptiles, viz. the 'hæmapophysis:' this element is called 'upper' and 'lower jaw' and 'horn of the hyoid' in the head, 'sternal rib' or 'cartilage of the rib' in the chest: the same element is retained to form the 'pelvis,' where it is called 'pubis' and 'ischium'; and it is continued as a distinct pair of bones in the beginning of the tail in the Great Ant-eater (Plate LIII., fig. 60, *h h*), and throughout a great part of the tail in the *Ichthyosaurus* and *Plesiosaurus*; whilst the pair of hæmapophyses become confluent at their distal ends, and form the so-called chevron-bones in the Crocodile, and most other Saurians. Under all these modifications the hæmapophyses coexist with pleurapophyses in the thorax, the pelvis and the tail; only in the latter region the pleurapophyses become anchylosed to the diapophyses or to the centrum, and stand out as 'transverse processes' (fig. 60, *d*, *pl*). The sudden diminution in the size of the hæmal arch in the tail, as contrasted with its expanse in the pelvis, is apt at first to excite some doubt as to the serial homology of the 'chevron bones' with the 'ischia' and 'pubes'; but when we compare them in a species, as *e.g.* the Mole (*Talpa*), in which the hæmal arch in the pelvis is limited to

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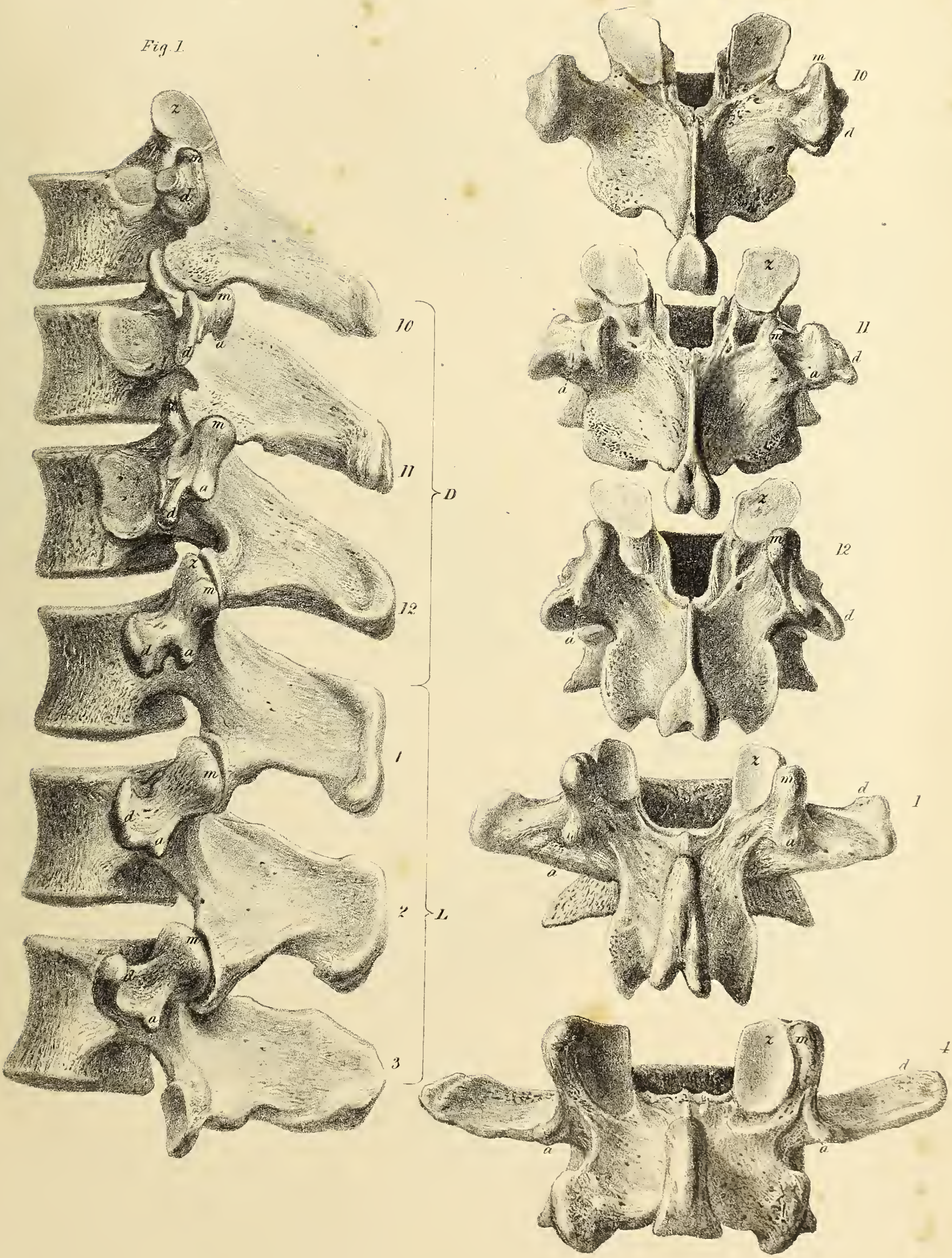
* Cuv. l. c. p. 224.

† Müller, Ueber den Bau und die Grenze der Ganoiden, und über das naturliche System der Fische, 1844.

‡ "Omnes arcus inferiores spinam gerunt e costis concretis formatam."—Franke, 'Nonnulla ad Amiam Calvam accuratius cognoscendam.'

Fig. 1

Fig. 2

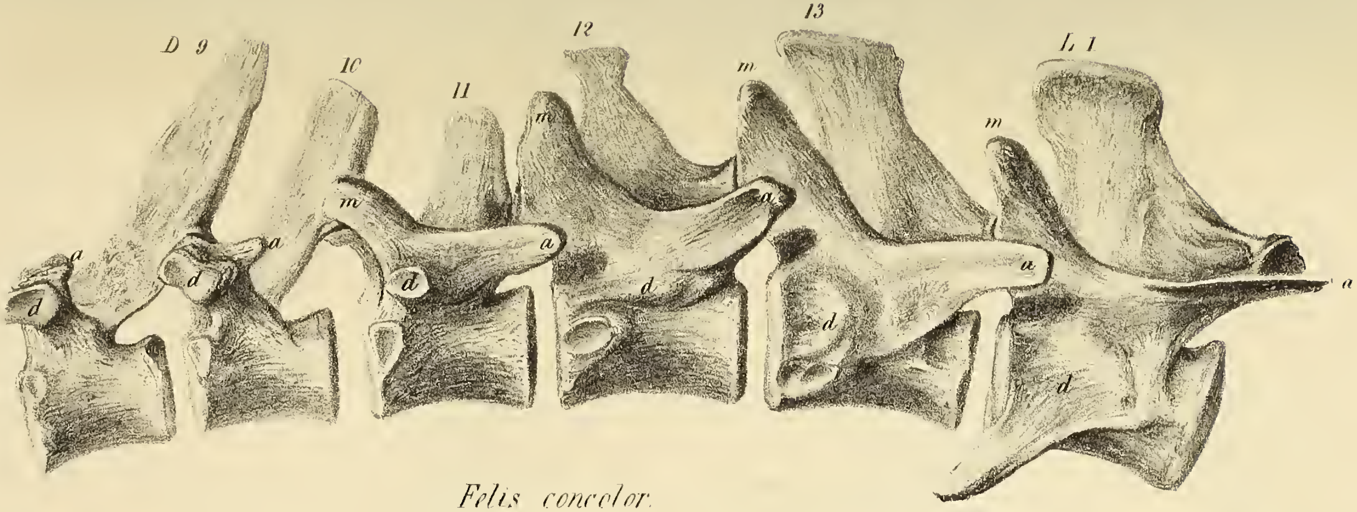


Homo

J. Dinkel del. et lith.

BRITISH MUSEUM NATURAL HISTORY.

Fig. 5.



Felis concolor.

Fig. 4.

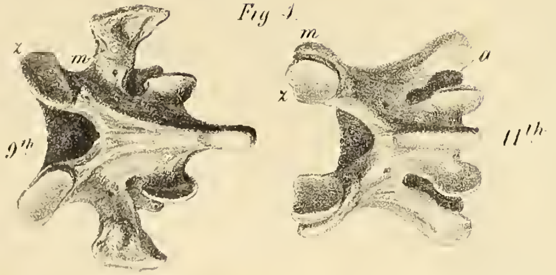


Fig. 6.

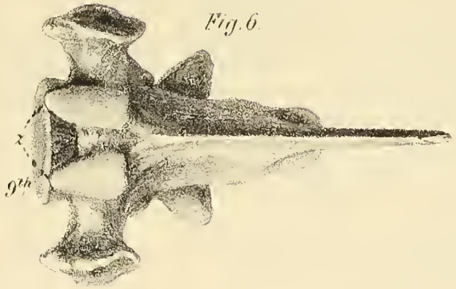


Fig. 7.

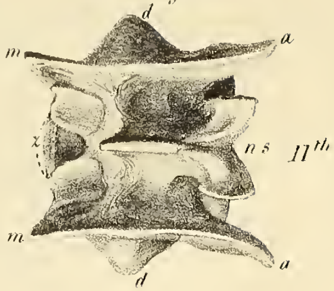
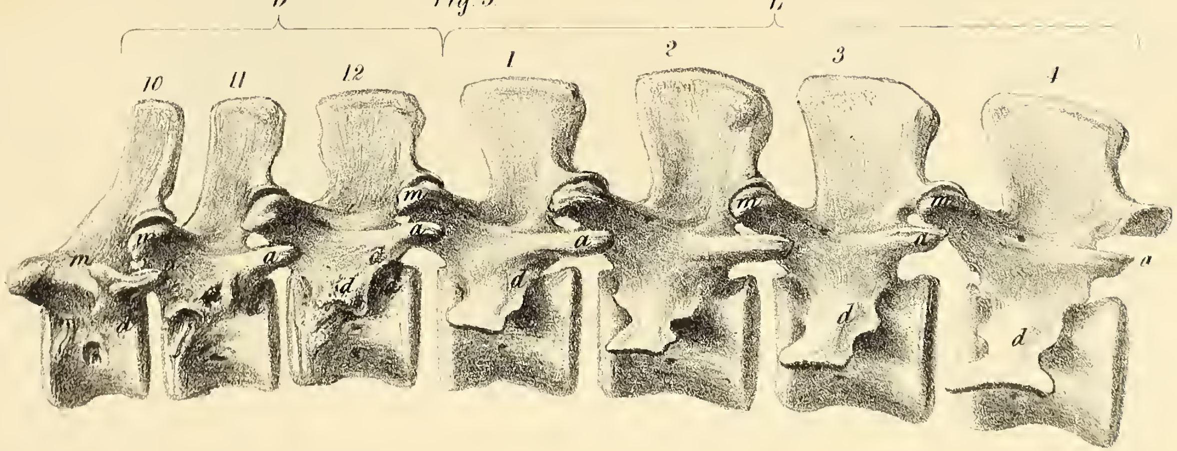


Fig. 3.



Macacus nemestrinus.

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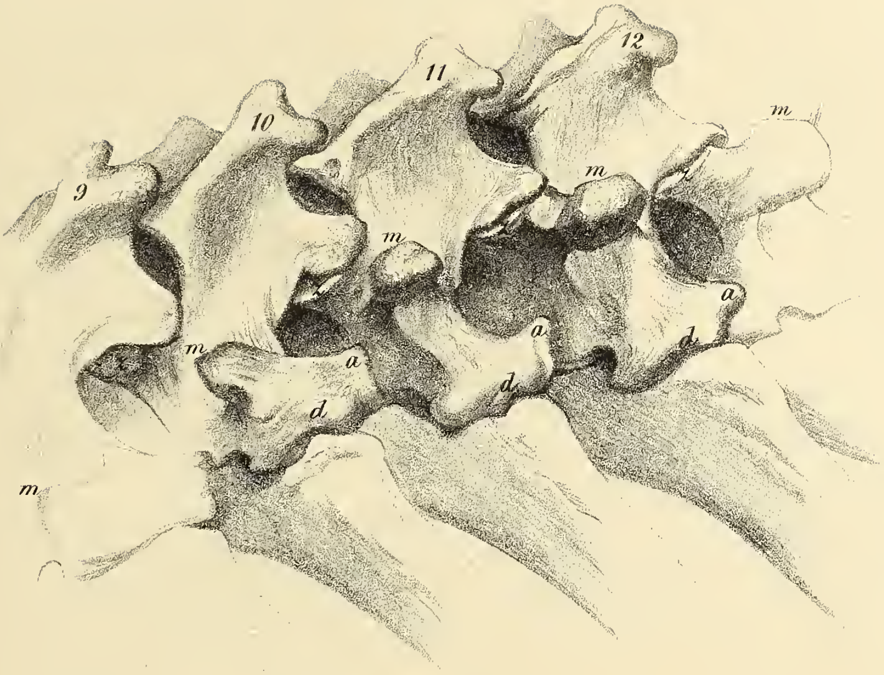
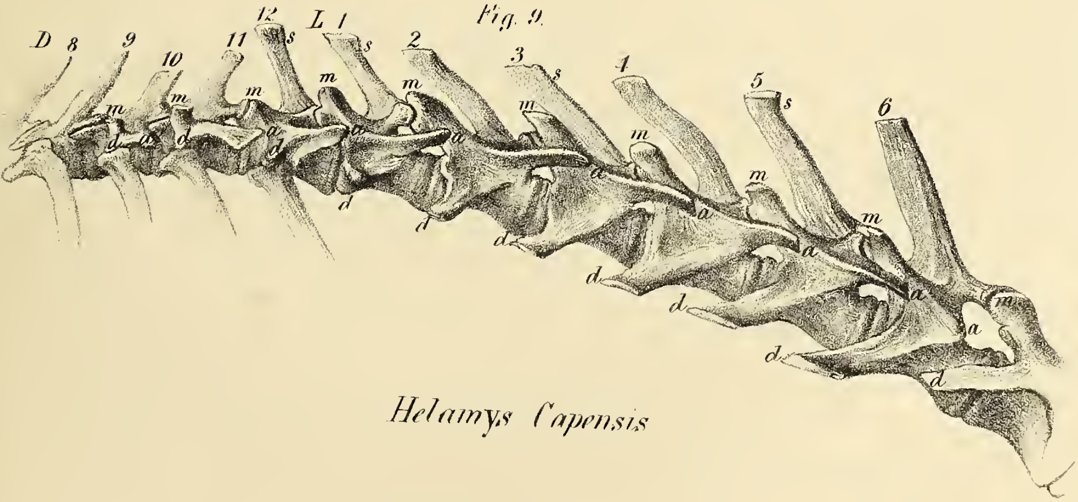
Fig. 8.



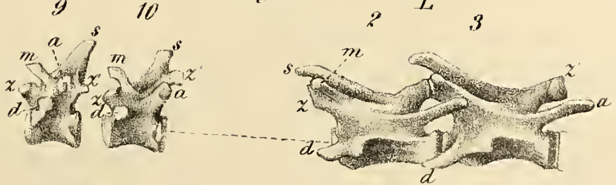
(Leptonyx) Phoca serridens.

Fig. 9.



Helamys Capensis

Fig. 10.



Lagotis

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the same protective functions as it performs in the tail of other quadrupeds, we find it reduced to the same small area or vertical dimensions, and applied close to the centrum, and the difficulty disappears. As the hypapophyses usually coexist with and support the hæmapophyses, when these are present in the tail of a reptile or mammal, they cannot be 'homologous' in any sense, and the hypapophyses are only 'analogous' when they happen to be perforated by the carotid arteries, as in the cervical vertebræ of some birds, or when they include the caudal artery and vein, as in the tail of Serpents. No one can confound the parapophyses or inferior transverse processes (Plate LII., fig. 52, *p*) with the hypapophyses (ib. *h*), who has observed them as they coexist in the cervical vertebræ of a Crocodile; and the hypapophyses are equally demonstrated to be distinct from the hæmapophyses by the presence of both in the tail of the *Myrmecophaga jubata* (Plate LIII., fig. 60, *hy*, *h*).

Description of the Plates.

In each figure the same processes are indicated by the same letters.

m. Metapophysis.
a. Anapophysis.
z. Zygapophysis.
d. Diapophysis.
p. Parapophysis.
hy. Hypapophysis.

PLATE XLIV.

Fig. 1. The three last dorsal and three first lumbar vertebræ of a Frenchman. Side view.

Fig. 2. The three last dorsal, first and fourth lumbar vertebræ of the same, from the dorsal aspect.

PLATE XLV.

Fig. 3. The three last dorsal and four first lumbar vertebræ of the Brown Monkey (*Macacus nemestrinus*), from the side.

Fig. 4. The tenth and eleventh dorsal vertebræ of the same, from the dorsal aspect.

Fig. 5. The five last dorsal and first lumbar vertebræ of the Puma (*Felis concolor*). Side view.

Fig. 6. The ninth dorsal vertebra of the same, from the dorsal aspect.

Fig. 7. The eleventh dorsal vertebra of the same, from the same aspect.

PLATE XLVI.

Fig. 8. An oblique upper view of the tenth, eleventh and twelfth dorsal vertebræ, to show the distinctness of the metapophysis (*m*) from the zygapophysis (*z*) and the diapophysis (*d*), and the gradual change of position of the metapophysis (*Leptonyx serridens*).

Fig. 9. The last five dorsal and the lumbar vertebræ of the *Helamys capensis*. Side view.

Fig 10. The ninth and tenth dorsal with the second and third lumbar vertebræ of the *Lagotis Cuvieri*. Side view.

PLATE XLVII.

Fig. 11. The last seven dorsal vertebræ of the Capybara (*Hydrochœrus Capybara*), from the dorsal aspect, chiefly to demonstrate the distinction between the metapophyses (*m*) and the prozygapophyses (*z*).

Fig. 12. The twelfth, fourteenth and fifteenth dorsal vertebræ, and the first and second lumbar vertebræ of the Wombat (*Phascolomys Wombatus*), from the dorsal aspect, to show the serial homology of the diapophysis (*d*), and the partially anchylosed rib (*pl*) of the first lumbar vertebra (L 1).

Fig. 13. The last four dorsal vertebræ, the lumbar vertebræ and sacrum of the *Macropus Parryi*, side view, showing the abrupt commencement of the metapophyses (*m*) on the twelfth dorsal, the comparatively small size of the anapophyses (*a*); and the distinctness and persistency of the diapophyses (*d*) in the posterior dorsal vertebræ.

PLATE XLVIII.

Fig. 14. The last eight dorsal vertebræ and first lumbar vertebra of the Musk-deer (*Moschus moschiferus*), showing the progressive development and change of position of the metapophysis (*m*); the serial homology of the dorsal and lumbar diapophyses (*d*); and the anomalous development of the pleurapophysis (*pl'*) of the fourteenth vertebra from the neck. Side view.

Fig. 15. The fourth, sixth, seventh, twelfth and fourteenth dorsal vertebræ of the *Delphinus Tursio*, from the dorsal aspect, showing the gradual supercession of the prozygapophyses (*z*), by the metapophyses (*m*).

Fig. 16. The eleven anterior dorsal vertebræ of the *Delphinus Delphis*, showing the sudden beginning and progressive ascent of the *metapophysis* (*m*) in that part of the vertebral column; also the progressive elongation of the diapophysis (*d*).

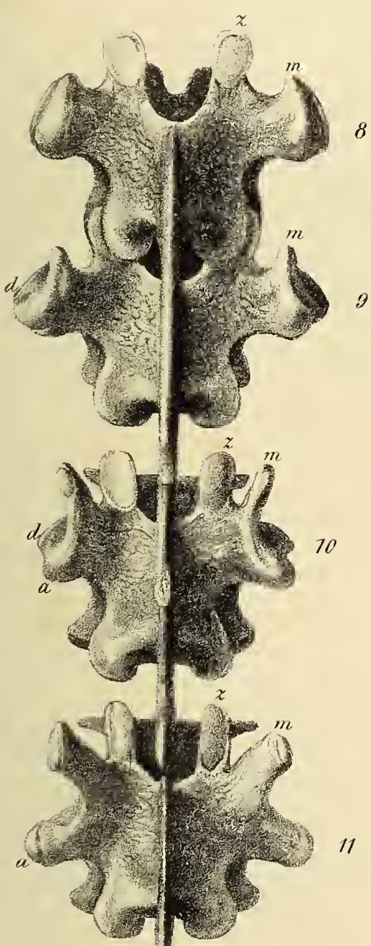
PLATE XLIX.

Fig. 17. The last two dorsal and first lumbar vertebræ of the Three-toed Sloth (*Bradypus tridactylus*), from the dorsal aspect.

Fig. 17*. The last six cervical and first two dorsal vertebræ of the *Echidna hystrix*, showing the distinct short and thick pleurapophyses (*pl'*) of the neck, still articulating with the diapophysis (*d*) and parapophysis (*p*).

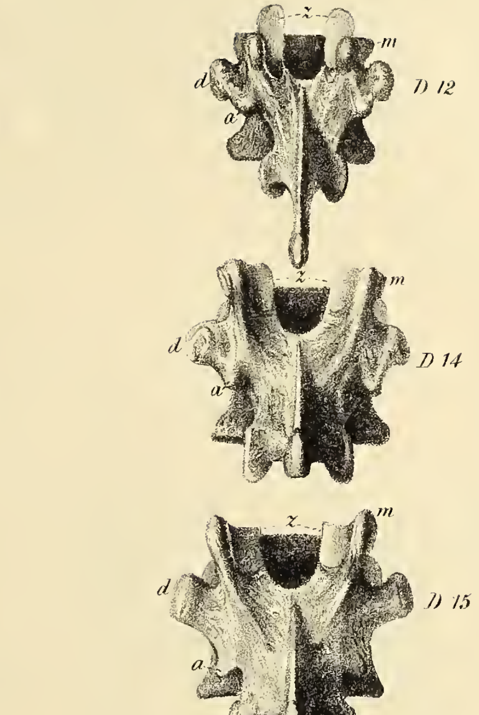
The body of the atlas (*c a*) has not yet coalesced, as the ‘odontoid process,’ with the dentata.

Fig. 11.



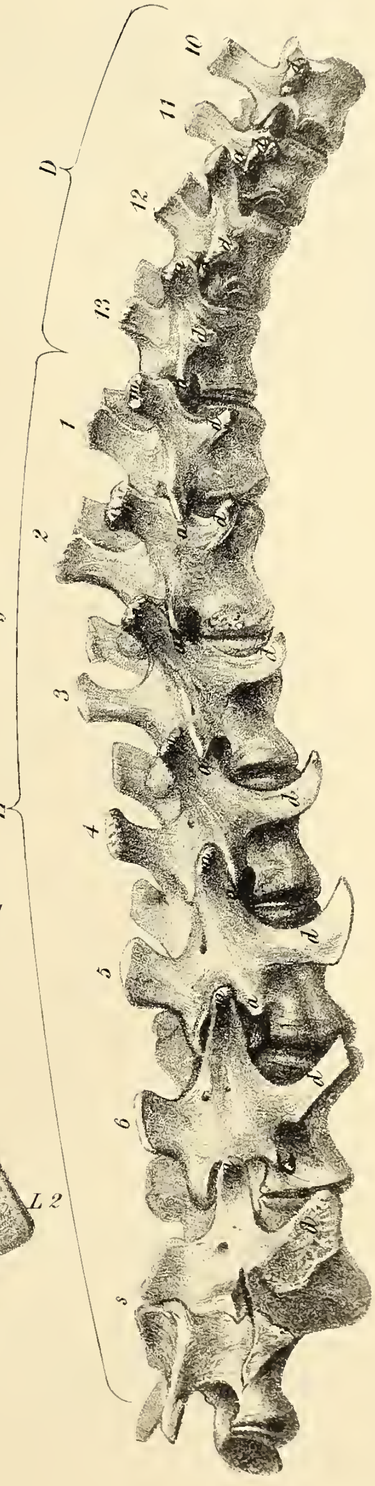
Hydrochœrus Capybara

Fig. 12.



Phascolomys Wombat

Fig. 13.



Macropus Parryi

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Delphinus Delphis.

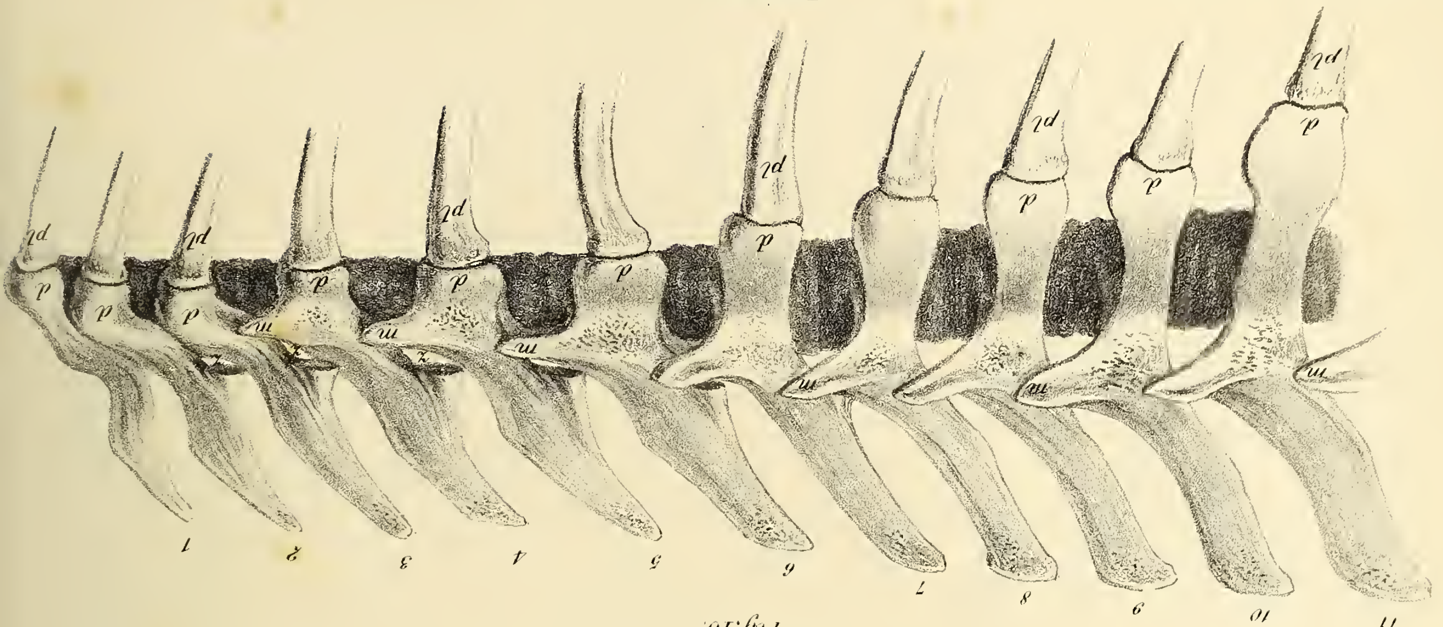
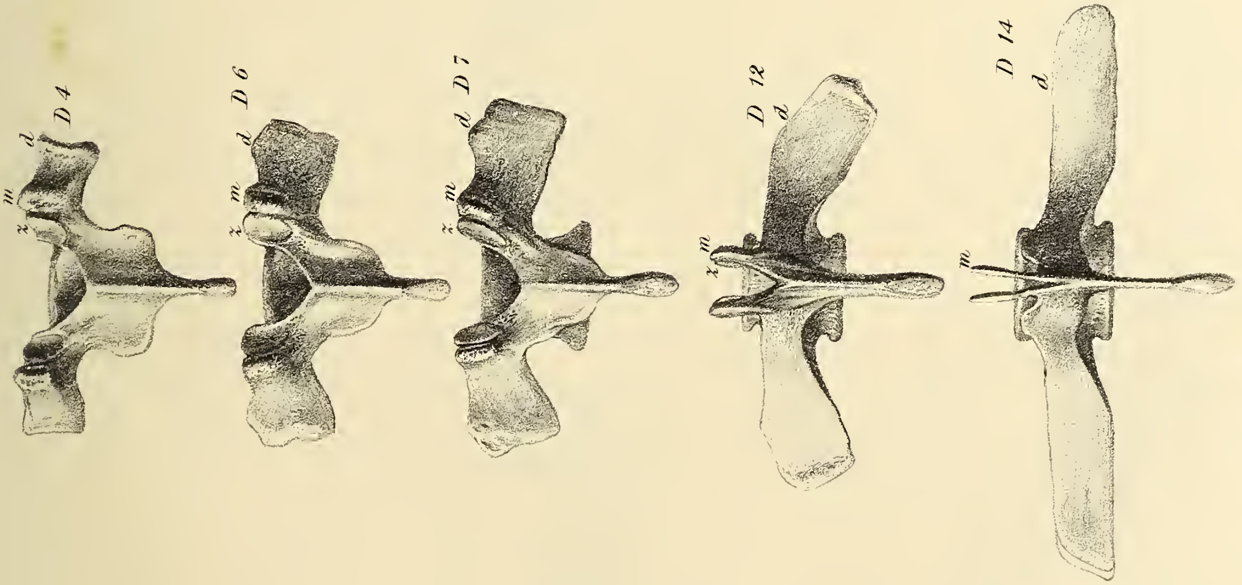


Fig. 16.

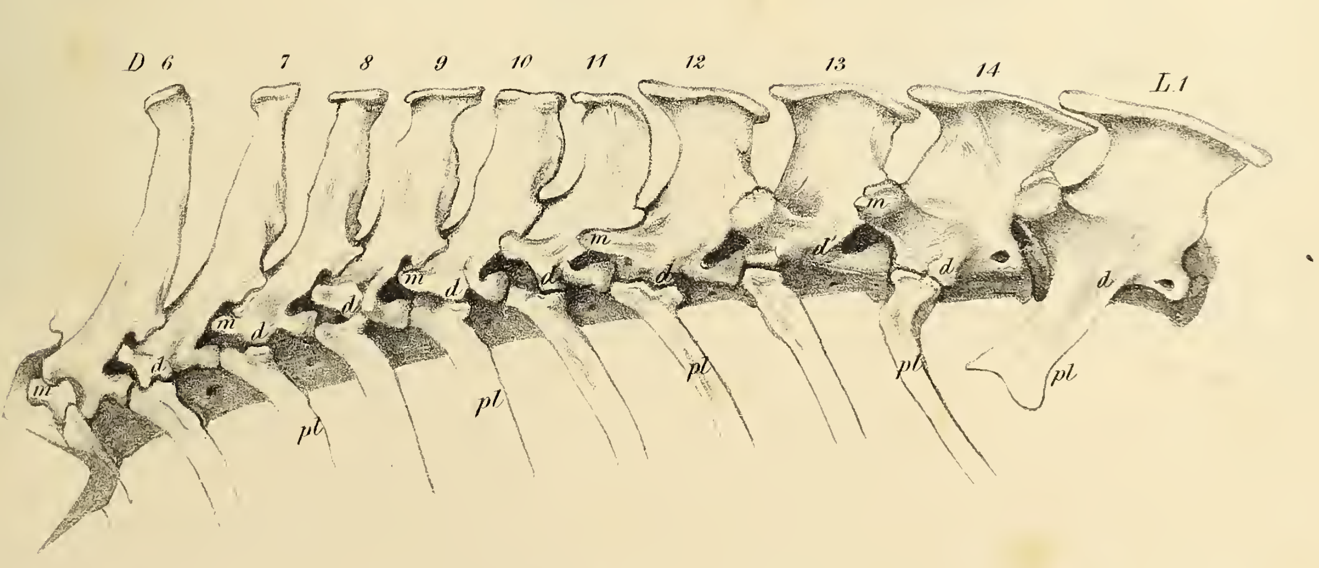
Fig. 15.



Delphinus Tursio.

½ nat. size.

Fig. 14.



Moschus moschiferus

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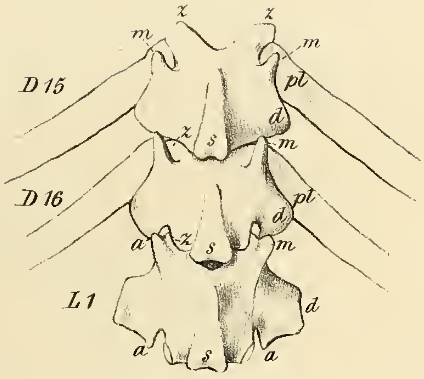
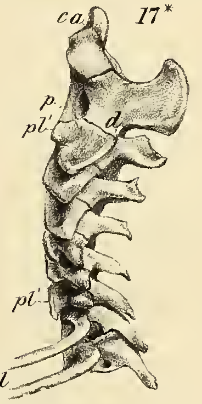
Fig. 17.

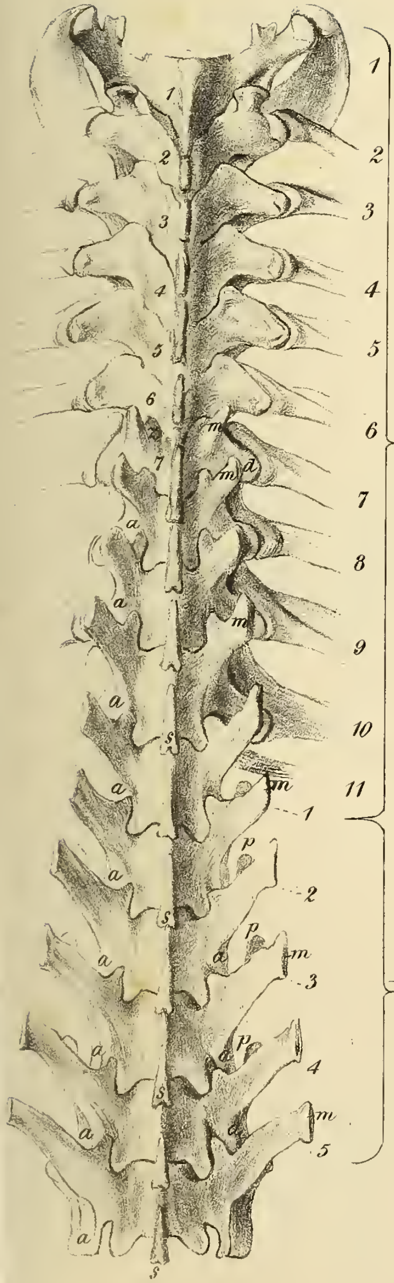


Bradypus tridact.s

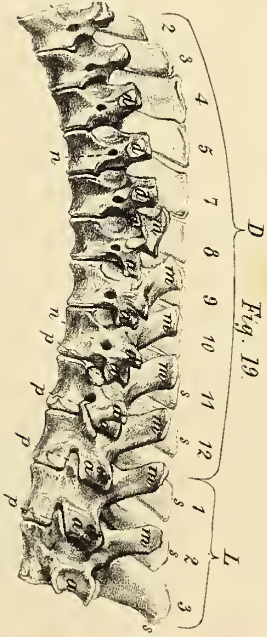


Echidna

Fig. 18.



Dasypus longicaudus



Dasypus tricinctus Fig. 19.

Myrmecophaga jubata

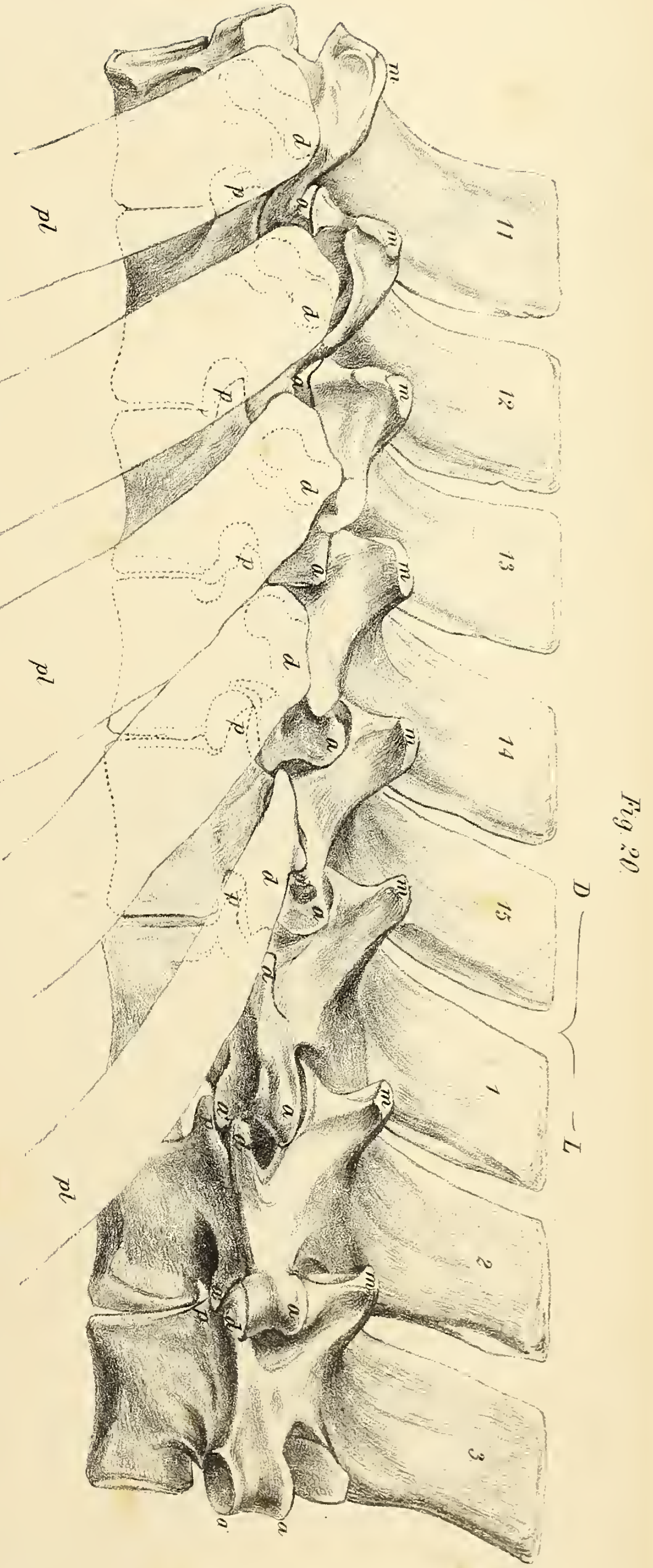


Fig. 20.

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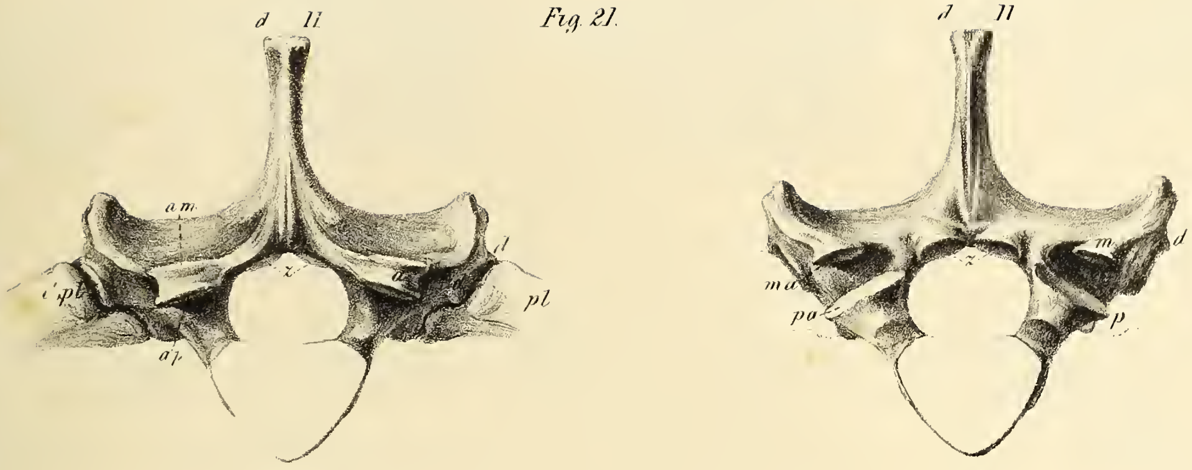
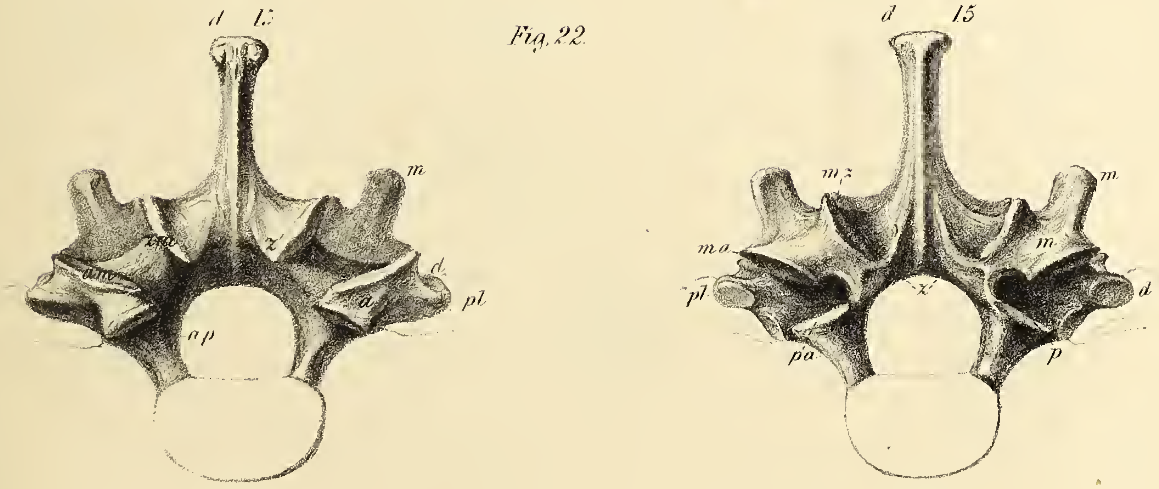
Fig. 21.



back

front

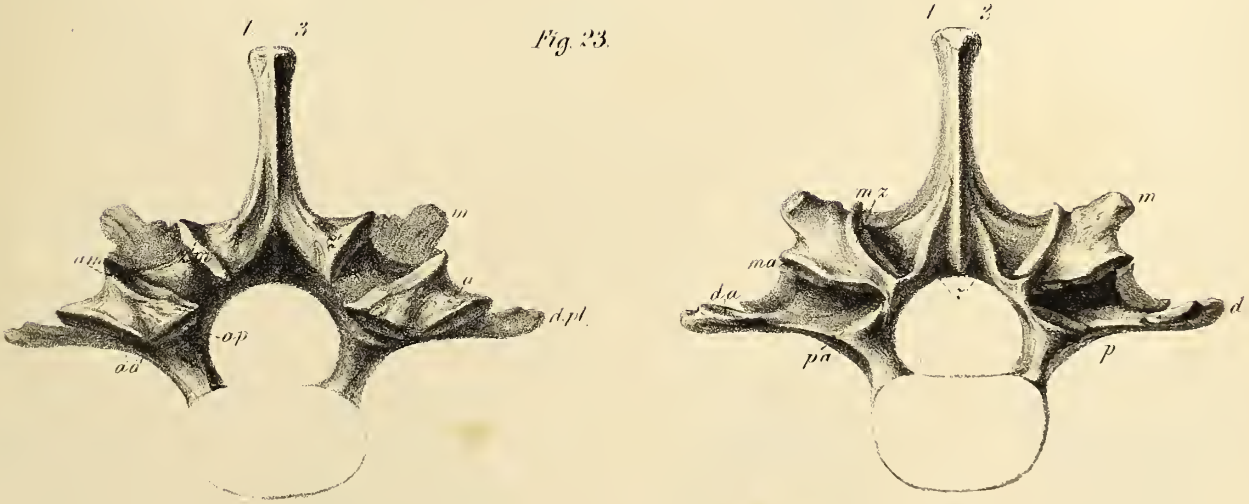
Fig. 22.



back

front

Fig. 23.



back

front

Myrmecophaga jubata.

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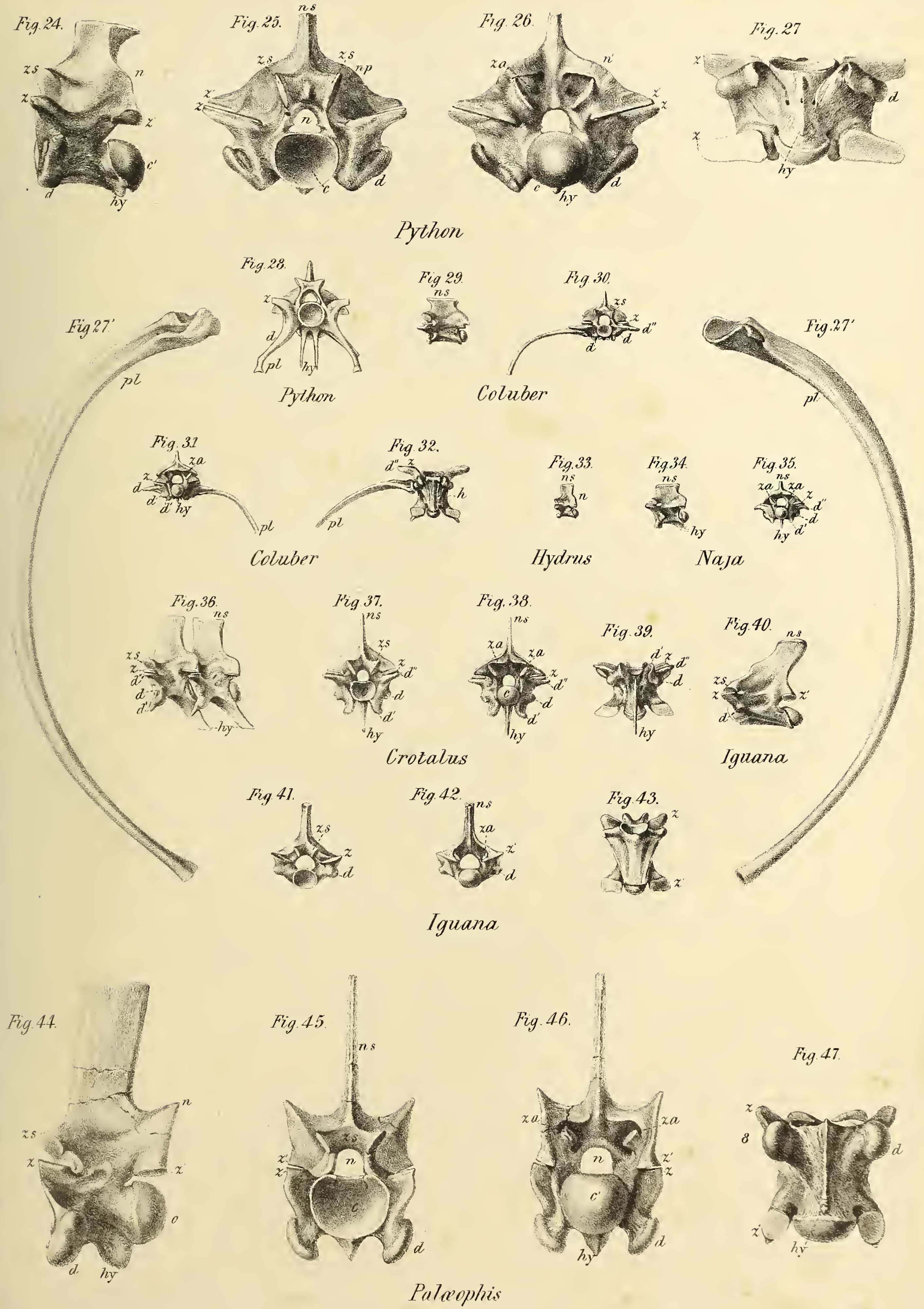

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Fig. 18. The eleven dorsal vertebræ and four of the lumbar vertebræ of the long-tailed Armadillo (*Dasypus longicaudus*), from the dorsal aspect, showing the abrupt commencement and great development of the metapophyses, *m*.

Fig. 19. The twelve dorsal vertebræ and three lumbar vertebræ of the Three-banded Armadillo (*Dasypus tricinctus*); a side view, showing the successive super-addition to the diapophyses (*d*), of metapophyses (*m*), anapophyses (*a*) and parapophyses (*p*); and the progressive development of the anapophyses and metapophyses.

Fig. 20. The last five dorsal and first three lumbar vertebræ of the Great Ant-eater (*Myrmecophaga jubata*), showing the progressive development of the metapophyses (*m*) and anapophyses ($a\ a'$), together with the diapophyses (*d*) and parapophyses (*p*). The pleurapophyses (*pl*) are left in outline. A side view.

PLATE L.

Fig. 21. Front and back views of the eleventh dorsal vertebra of the same Ant-eater, showing—

- *p*. The parapophysis; *p a*, its articular surface.
- *d*. The diapophysis; *d, pl*, its articular surface for the pleurapophysis.
- *m*. The metapophysis; *m a*, its articular surface for the anapophysis.
- *a*. The anapophysis; *a p*, its articular surface for the parapophysis; *a m*, its articular surface for the metapophysis.
- *z*. The anterior zygapophyses, with articular surfaces looking upwards.
- z'. The posterior zygapophyses, with articular surfaces looking downwards.
- *pl*. Head and tubercle of pleurapophysis.

Fig. 22. Front and back views of the last (15th) dorsal vertebræ; which in addition to the parts specified above, shows—

- *mz*. The articular surface of the metapophysis for the modified or newly developed posterior zygapophysis (z').
- *zm*. The articular surface of the posterior zygapophysis for the metapophysis.

The ordinary zygapophyses are almost suppressed.

Fig. 23. Front and back views of the third lumbar vertebra, which besides the parts specified above, shows—

- *da*. The articular surface on the diapophysis for the anapophysis.
- *ad*. The articular surface on the anapophysis for the diapophysis.

PLATE LI.

Fig. 24. Side view of a middle trunk-vertebra of the *Python Sebæ*.

Fig. 25. Front view of ditto.

Fig. 26. Back view of a middle trunk-vertebra of the *Python Sebæ.*
Fig. 27. Under view of ditto.
Fig. 27'. Vertebral ribs or 'pleurapophyses' of the *Python.*
Fig. 28. Front view of a middle tail-vertebra of ditto.
Fig. 29. Side view of a middle trunk-vertebra of the *Coluber elaphus.*
Fig. 30. Front view of ditto, with one of the ribs.
Fig. 31. Back view of ditto.
Fig. 32. Under view of ditto.
Fig. 33. Side view of a middle trunk-vertebra of the *Hydrus bicolor.*
Fig. 34. Side view of a middle trunk-vertebra of *Naja.*
Fig. 35. Back view of ditto.
Fig. 36. Side view of two middle trunk-vertebræ of the *Crotalus durissus.*
Fig. 37. Back view of ditto.
Fig. 38. Front view of ditto.
Fig. 39. Under view of ditto.
Fig. 40. Side view of a middle trunk-vertebra of the *Iguana.*
Fig. 41. Front view of ditto.
Fig. 42. Back view of ditto.
Fig. 43. Under view of ditto.
Fig. 44. Side view of a middle trunk-vertebra of the *Palæophis typhæus.*
Fig. 45. Front view of ditto.
Fig. 46. Back view of ditto.
Fig. 47. Under view of ditto.

The same letters indicate the same parts in each figure:—

c. The centrum.
d. The diapophysis, its articular tubercle.
d'. Its inferior production.
d''. Its superior production.
z. The anterior zygapophysis.
z'. The posterior zygapophysis.
ns. The neural spine.
n. The neurapophysis, produced into an angle in *Palæophis.*
pl. The pleurapophysis.
zs. The zygosphene.
za. The zygantrum.
hy. The hypapophysis.

PLATE LII.

Fig. 48. The five last cervical and five first dorsal vertebræ of the Great Penguin (*Aptenodytes patachonica*): an under view, showing the great development and metamorphoses of the hypapophyses (*h*).

Fig. 48.

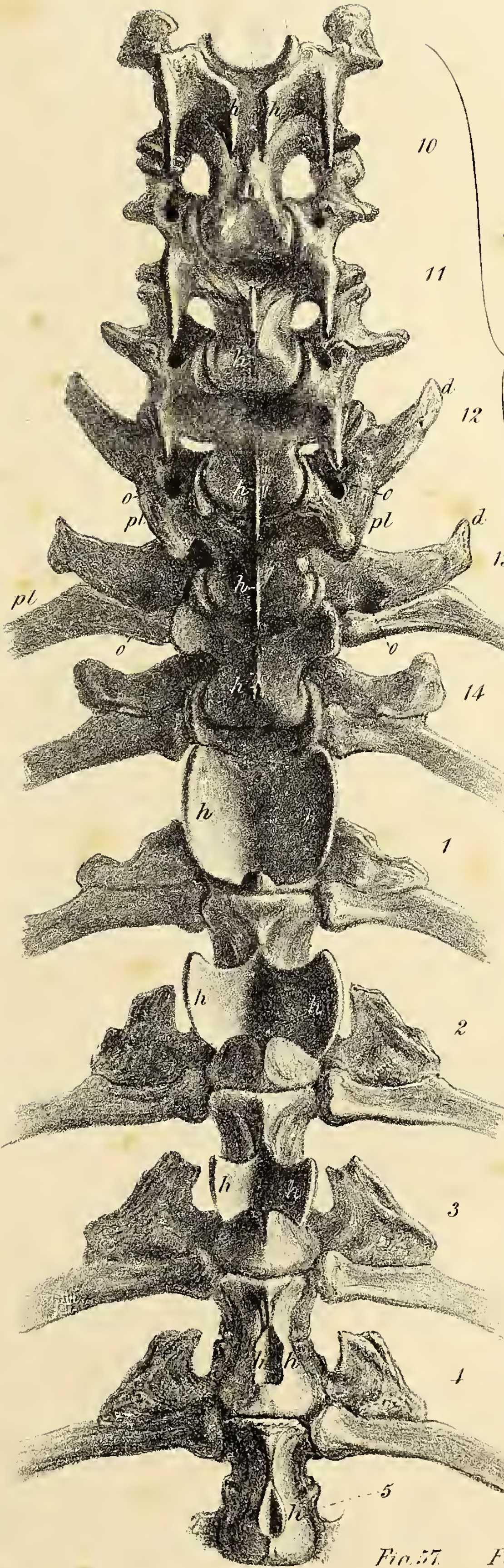
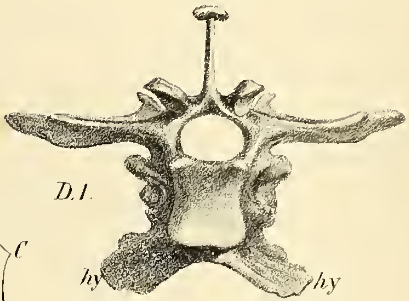


Fig. 49.



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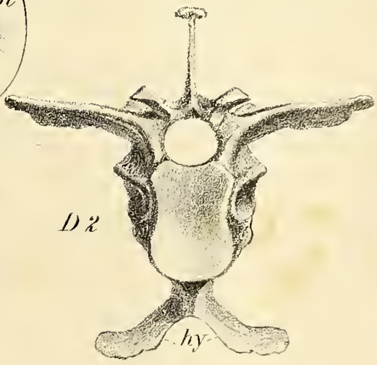


Fig. 51.

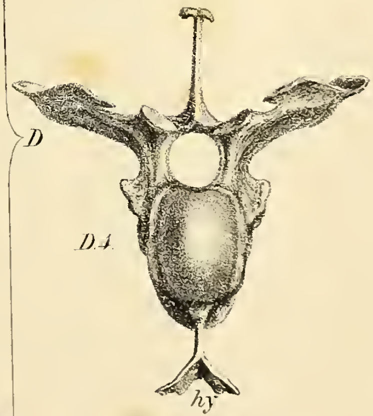


Fig. 53.

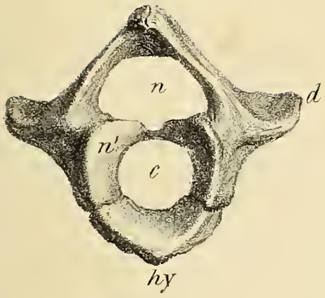


Fig. 52.

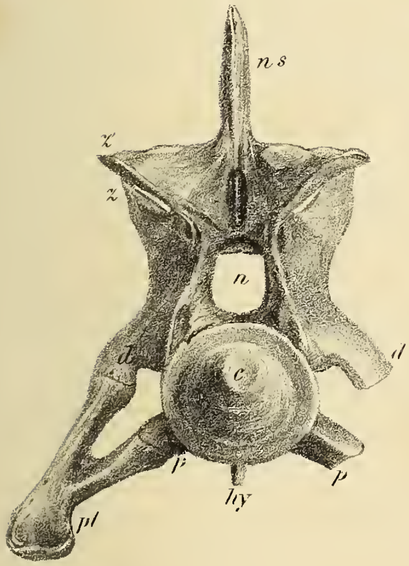
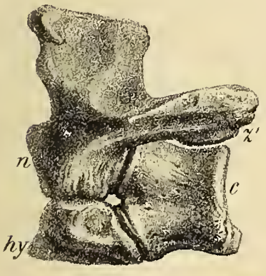


Fig. 54.



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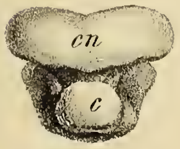
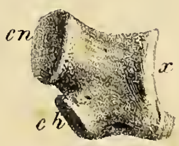


Fig. 56.



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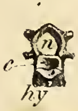


Fig. 58.

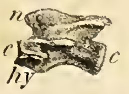
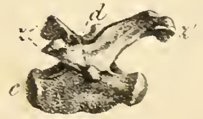


Fig. 59.



Aptenodytus Patagonica

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Fig. 49. A back view of the first dorsal vertebra, showing the diverging hypapophysial plates (*hy*, *hy*).

Fig. 50. A back view of the second dorsal vertebra, showing the common base of the diverging plates (*hy*, *hy*).

Fig. 51. A front view of the fourth dorsal vertebra, showing the elongated base of the bifurcating hypapophysis (*hy*). In this vertebra the anterior surface of the centrum is simply convex, the posterior surface concave.

Fig. 52. A back view of the third cervical vertebra of a Crocodile, showing the diapophysis (*d*) and the parapophysis (*p*), or the upper and lower transverse processes of the right side; and the same, on the left side, with the co-articulated 'pleurapophysis' (*pl*) or 'hatchet-bone.' *c* is the ball on the back part of the centrum; *n* the neural arch; *ns* the neural spine; *z* is the prozygapophysis; *z'* the zygapophysis; *hy* the hypapophysis.

Fig. 53. Front view of part of the atlas of a Soft-tortoise (*Trionyx Dumerili*, O.). *c* the vacant space left by the absent centrum; *hy* the hypapophysis or 'wedge-bone'; *n* the neural canal; *n'* the anterior articular surface of the neurapophysis; *d* the diapophysis.

Fig. 54. Side view of the atlas of the same *Trionyx*. *c* the centrum; *hy* hypapophysis; *n* neurapophysis, its anterior articular process or prozygapophysis; *z'* zygapophysis.

Fig. 55. Anterior view of the centrum of the atlas, showing *c* its articular surface for the hypapophysis; *c n* its articular surface for its neurapophyses, and for the basioccipital or centrum of the occipital vertebra.

Fig. 56. Side view of the same; *x* the concave articular surface for the centrum of the dentata.

Fig. 57. Front view of the atlas of the Long-necked Tortoise (*Hydraspis longicollis*, BELL).

Fig. 58. Side view of the same vertebra. The centrum *c* ('odontoid process' of Anthropotomy) has coalesced with its neural arch *n*, and the typical character of the atlas, as it is manifested in the class of fishes and in enaliosaurians, is resumed; *hy*, the hypapophysis ('body of the atlas' in Anthropotomy).

Fig. 59. The eighth cervical vertebra of the *Hydraspis longicollis*, which, like the first caudal vertebra of the Crocodiles*, is biconvex; *c* the centrum; *z* the two prozygapophyses; *z'* the postzygapophysis; *d* the two diapophyses.

PLATE LIII.

Fig. 60. A front view of the first caudal vertebra of the Great Ant-eater (*Myrmecophaga jubata*).

c. The centrum.
n, *n*. The neurapophyses.

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* Physiological Catalogue of the Museum of the Royal College of Surgeons, vol. i. (1833) p. 53, Prep. No. 250.

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